Modelling the macroeconomic and fiscal impact of climate and energy policies in Slovenia

D5: Final modelling framework and final technical note with recommendations to improve and further develop the modelling framework

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Contents

1 Objective

This report is the final technical and user manual of the GEM-E3-SI model. The technical manual serves as a methodological and technical guide of the GEM-E3-SI, outlining the theory upon which the model is built and the mathematical formulations for all the equations of the model. The user guide provides the GEM-E3-SI user with instructions on the user interface and operation of the model while it provides guidance to perform different policy simulations.

This report includes a detailed description of the models dataset, the base year calibration and the steps taken to produce a Baseline and policy scenarios.. The model code is written in GAMS and a complete dataset in spreadsheet format is produces and delivered to the Slovenian authorities.

This report provides the key assumptions and projections of the Slovenian economy until 2050 under a Baseline context, quantified using the GEM-E3-SI model. Results for diagnostic and policy scenarios are presented and recommendations on how to improve and further develop the modelling framework are provided.

This report is structured as follows: the next section presents the technical manual of the model. Section 3 focuses on the user manual. Section 4 presents the Baseline scenario for the Slovenian economy. Sector 5 regards the key diagnostic and policy scenarios and the last section provides recommendations on how to further improve the modelling framework.

2 Technical manual

Overview

The GEM-E3-SI model is a Computable General Equilibrium (CGE) model developed specifically for Slovenia. The model has been developed by E3-Modelling with funding from DG REFORM of the European Commission in order to provide analytical support to the Slovenian authorities, particularly with regards to the economics of climate change. Applications of the model have been carried out for the development of as Baseline scenario and alternative policy scenarios (as pilots) for Slovenia.

GEM-E3-SI model is a multi-regional model where Slovenia is included individually, EU is represented in one large group (rest of EU27 member states) and the rest of the world is grouped into one large region (rest of the world countries). GEM-E3-SI is a multi-sectoral model representing individually 50 production activities, including the detailed representation of the power generation and electricity sectors. The model is recursive dynamic and focus on macroeconomic adjustments and their links with the environment and the energy systems. GEM-E3-SI is a large scale model written entirely in structural form. The model allows for the consistent comparative analysis of policy scenarios since it ensures that in all scenarios, the economic system remains in general equilibrium. The model incorporates the micro-economic mechanisms and institutional features within a consistent macro-economic framework and avoids the representation of behavior in reduced form. Particularly valuable are the insights the model provides regarding the distributional aspects of long-term structural adjustments. The model includes projections of full Input-Output tables by country/region, national accounts, employment, balance of payments, public finance and revenues, household consumption, energy use and supply, GHG emissions and atmospheric pollutants. The formulation of the GEM-E3-SI allows for the integration of parameter values and calibration information from more detailed bottom-up models. Bottom-up models are self-operating within the context of the CGE modelling and their mathematical form is kept compact so as to minimize the impact on the solving time required for the simulation of the scenarios.

Theoretical foundations, general presentation and policy analysis application

General equilibrium modelling core features derive from the Arrow-Debreu (1954) economic equilibrium theorem and its constructive proof of existence based on the Brower-Kakutani theorem. According to the Arrow-Debreu theorem the economy is considered as a set of agents, divided in suppliers and consumers, interacting in several markets for an equal number of commodities. Each agent is a price-taker as market interactions and not the agent set the prices. Each agent is individually defining his/her supply or demand behavior by optimizing his own utility, profit or cost objectives. Under general conditions, there exists a set of prices that bring supply and demand quantities in equilibrium, and all agents individually are fully satisfied. The Brower-Kakutani existence theorem is constructive in the sense of implementing a sort of tatonnement process around a fixed point where the equilibrium vector of prices stands. Models that follow such a process are called computable general equilibrium (CGE) models. The development of the CGE models has advanced significantly from their initial development based on macro-micro integration (*IS-LM* mechanism) traditionally used in Keynesian models, to modelling market imperfections in the goods or labour market and other economic mechanisms that deviate from the Pareto optimality frontier, to the introduction of alternative market clearing regimes and the new trade economic theory[1] and to the incorporation of mechanisms reflecting endogenous technology evolution dynamics[2]. The current stream of CGE models, through a modular design, covers the entire area of modern economics extending considerably further than the standard neo-classical economics on which the first generation of CGE models was based. This new generation of model design is the basis of the development of the GEM-E3-SI model.

GEM-E3-SI model is a CGE model specific to Slovenia which includes the interactions of the country with the rest of the world. The model covers the whole world aggregated in 3 countries/regions (Table 1) where Slovenia is represented individually. The rest of the world countries are grouped into the rest of EU27 countries, and the rest of the world. The model is a multi-sectoral recursive dynamic CGE model driven by accumulation of capital and equipment which provides details on the macro-economy and its interactions with the environment and the energy system. The model covers individually 50 activities including the detailed representation of the power generation technologies (Table 2). The model is written in structural form. The model can be used for the comparative analysis of alternative policy scenarios and the provision of insights on the distributional effects of long-term structural adjustments. In all simulation alternatives the model ensures that the economic system is found in general equilibrium. The model extends beyond the static comparison of alternative policies. The model is dynamic in the sense that projections change over time. The properties of the model are manifested through stock-flow relationships, technical progress, capital accumulation and agents' (myopic) expectations.

The GEM-E3-SI model is written in GAMS while supported by scripts in R and visual basic macro commands. The implementation of the model is split in two stages:

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[1] Helpman and Krugman (1985) describe the theoretical framework, while Baldwin (1992), Dewatripont and Ginsburgh eds. (1994) and Baldwin and Venables (1995) give examples of applications and overview of attempts.

[2] Grossman and Helpman (1991) provide the first systematic survey of incorporating endogenous growth mechanisms.

- **Calibration**: At this stage the calculation of the model parameters is carried out so that the model replicates a single year (base year) data.
- **Scenario quantification**: The model performs a dynamic projection of the full system and performs counterfactual analysis.

The model is built in modules enabling the user to choose between different closure options and market institutional regimes the choice of which rests with the modeler and the policies under consideration.

Table 1: Country-Regional aggregation of the GEM-E3-SI model

No.	Country/ Region
1	Slovenia
2	Rest of EU27
3	Rest of the World

Table 2: Sectoral aggregation of the GEM-E3-SI model

Agriculture		Industries		Power Generation	
AGR01	Agriculture	IND01	Ferrous metals	PGT01	Coal fired
Energy Sectors		IND02	Non-ferrous metals	PGT02	Oil fired
ENE01	Coal	IND03	Fabricated Metal products	PGT03	Gas fired
ENE02	Crude Oil	IND04	Chemical Products	PGT04	Nuclear
ENE03	Oil	IND05	Basic pharmaceutical products	PGT05	Biomass
ENE04	Gas	IND06	Rubber and plastic products	PGT06	Hydro electric
ENE05	Power Supply	IND07	Paper products, publishing	PGT07	Wind
ENE06	Biomass Solid	IND08	Non-metallic minerals	PGT08	PV
ENE07	Biofuels	IND09	Computer, electronic and optical products	PGT09	Geothermal
ENE08	Hydrogen	IND10	Other Equipment Goods	PGT10	CCS coal
ENE09	Clean Gas	IND11	Transport equipment (excluding EV)	PGT11	CCS Gas
Transport Sectors		IND12	Consumer Goods Industries	PGT12	CCS Bio
TRA01	Warehousing and support activities	IND13	Construction		
TRA02	Air transport	IND14	Batteries		
TRA03	Land transport	IND15	EV Transport Equipment		
TRA04	Water transport	IND16	Advanced Electric Appliances		
Services Sectors		IND17	Advanced Heating and Cooking Appliances		
SRV01	Market Services	IND18	Equipment for wind power technology		
SRV02	Non Market Services	IND19	Equipment for PV panels		
SRV03	R&D	IND20	Equipment for CCS power technology		
		IND21	CO2 Capture		

The model includes simultaneously all interrelated markets and represents the system at the appropriate level with respect to geography, the sub-system (energy, environment, economy) and the dynamic mechanisms of agents' behavior.

The GEM-E3-SI model includes the separate formulation of the supply and demand behavior of the economic agents which are considered to optimize individually their objective. Prices are computed by the model as a result of supply and demand interactions in the markets and guarantee global equilibrium. The production technologies are formulated endogenously in the model enabling the price-driven setting of intermediate consumption and the services from capital and labour. The model makes provision for the representation of technological progress in the production function.

The design of the GEM-E3-SI model is developed on the basis of a fully flexible setting of production and consumer's demand coefficients. Coefficients are flexible in the sense that producers can alternate the mix of production not only regarding the primary production factors but also the intermediate goods. Production is modelled through capital, labour, energy and materials (*K, L, E, M*) production functions involving all intermediate products and three primary factors of production namely: capital, natural resources and labour. Consumers make endogenous decisions on the demand structure for goods and services. Consumption is associated with a flexible expenditure which includes demand for durable and non-durable goods.

The model includes the institutional regimes which impact on agents' behavior such as public finance, taxation and social policy. GEM-E3-SI also makes provision for the internalization of environmental externalities. This is achieved through taxation or global system constraints, the shadow costs of which affect the decision of the economic agents. The model quantifies the environmental impact by calculating the change in emissions and damages and it determines the costs and the benefits through an equivalent variation measurement of global welfare inclusive of the environmental impact.

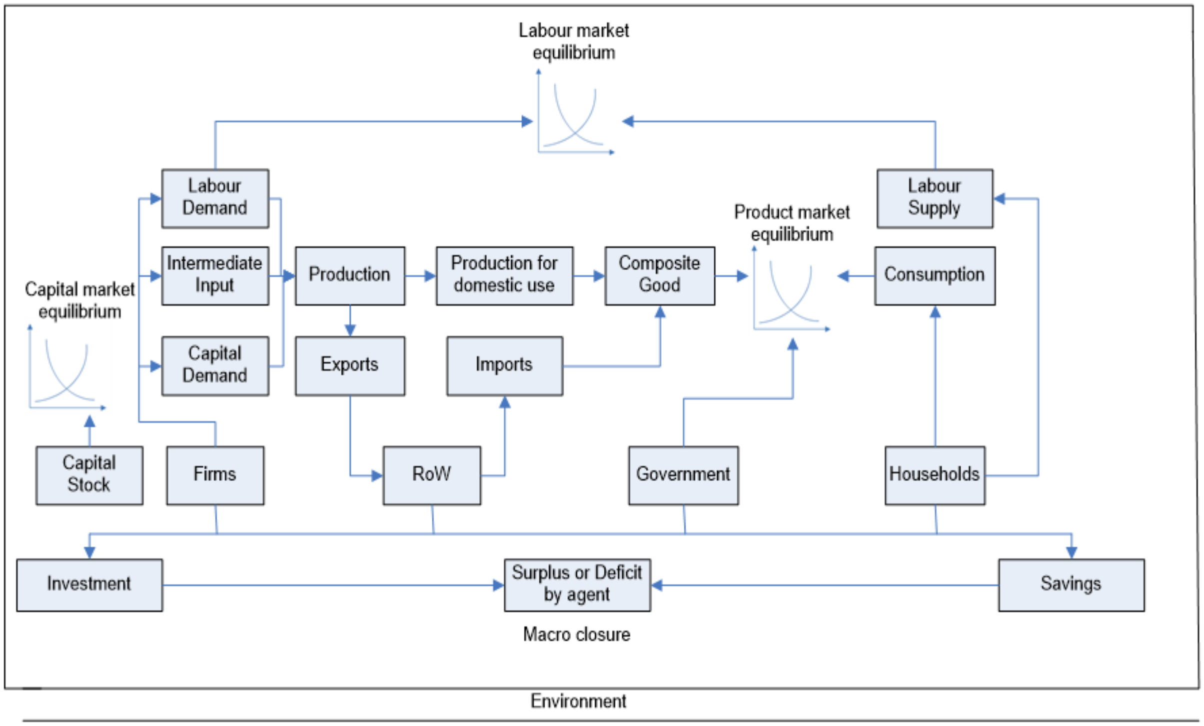
Consumption and investment is built around matrices linking consumption by purpose to demand for goods and investment by origin to investment by destination. In doing so the model includes a detailed treatment of taxation and trade. Bilateral trade flows are calibrated for each sector represented in the model, taking into account trade margins and transport costs. Total demand (final and intermediate) in each country is optimally allocated between domestic and imported goods, under the hypothesis that the latter are imperfect substitutes (see Armington, 1969).

The model is calibrated to base year data. Model calibration makes use of the latest available data for Slovenia available in GTAP and EUROSTAT. The model calibration is followed by the definition and the simulation of the reference scenario. The reference scenario includes all the policies being in place. The drivers of growth are labour force, total factor productivity and the expectations on sectoral growth. Once the reference scenario is set counterfactual scenarios can be run. The alternative scenario building process regards the computation of counterfactual equilibria by running the model under assumptions that diverge from those of the reference scenario. Thus a scenario is defined as a set of changes of exogenous variables which are imposed on top of the assumptions of the reference scenario hence modifying it. Scenario simulation does not necessitate model re-calibration. The counterfactual scenario can be accessed on the grounds of the changes induced in consumer's welfare or through the equivalent variation of his/her welfare function. The sign of the change of the equivalent variation provides a measure of the policy's impact and burden sharing implications. The model is formulated as a simultaneous system of equations with an equal number of variables. The system is solved for each year following a time-forward path.

GEM-E3-SI model develops on the basis of detailed Social Accounting Matrixes (SAMs) which provide a snapshot of the flows between production sectors, production factors and economic agents (households, firms, government and the foreign sector). The production sectors in GEM-E3-SI produce an equal number of distinct goods or services, as in an Input-Output table. The economic agents own primary production factors from which they receive income and capital rewarding. Part of the agents' income is used for consumption and investment which form the final domestic demand. Transactions with the foreign sector are captured through exports and imports. The surplus or deficit of economic agents is determined by the difference between income and spending. Firms are modelled to maximize their profits constrained by the physical capital stock and the available technology. Capital stock is fixed within the current period but it can change over time through investment that firms undertake. Households are modelled via a single representative household which maximizes its inter-temporal utility under an inter-temporal budget constraint. The demand functions are derived by solving the maximization problem, under general assumptions regarding expectations and steady state conditions. These demand functions allocate the expected income of the household, depending on the formulation of the problem, between consumption of goods and future consumption i.e., savings. The model includes an explicit allocation mechanism of household consumption which distinguishes between durable (cars, heating and electric appliances, etc.) and linked non-durable goods (energy i.e., fuels and electricity).

The building blocks of the GEM-E3-SI model include household, firms, government, the external sector and the environment (Figure 1). The model considers the micro-theory of the agents' behavior and the macro flows and interactions among them. The model captures the macro-economic effects of policy changes by considering the changes at micro level that the latter induce. For instance imposing a carbon tax affects the production costs of the firms which react by changes in the shares of inputs to production (substitution of cheaper alternatives for polluting technologies). This affects the capital returns, thus investments and the disposable income of households. In their turn households alternate their consumption decisions. Changes in the consumption decision and production mix impact on the flows recorded with the external sector and on government revenues. The model structure allows for a complex macro simulation compatible with the micro theory.

Figure 1 GEM-E3-SI model schematic representation



Source: GEM-E3-SI

GEM-E3-SI model can be a useful tool in the assessment of alternative policies and their economic and welfare impact. Policies are analyzed as counterfactual dynamic scenarios and are compared against reference model runs. Policies are then evaluated through their impact on sectoral growth, finance, income distribution and global welfare. The GEM-E3-SI model can deal with questions regarding the conditions under which economic growth, and its distributional pattern, can be sustained in the presence of environmental constraints or energy shortages and even reinforced by means of an adequate technological and market-oriented policy. The model can analyze climate change policies and their interactions within the economy, energy and environment systems. The model can also support the analysis of distributional effects both among countries and among social and economic groups within each country.

Data sources, structure, manipulation

The development of the GEM-E3-SI model requires substantial data inputs from a range of data sources. Data requirements of the GEM-E3-SI model include: detailed Social Accounting Matrices for every country/region included in the model, detailed bilateral trade, investment and consumption matrices, data on energy balances, emissions and pollutants, demographic and labour market data, fiscal data (like tax rates) and other macroeconomic data (like interest rates and consumer price indices).

Table 3 summarizes the data sources used and the data used in the model. For the construction of the GEM-E3-SI database two main sources of IO tables have been used, namely: the Eurostat database and the Global Trade Analysis Project (GTAP)[3] database. EUROSTAT provides IO tables for its member states for a 56 economic activity aggregation. The latest data of EUROSTAT which can be used for the GEM-E3-SI model regard year 2015. Eurostat alone cannot support the calibration of a global model, thus further IO data from the GTAP model were used. The GTAP database covers the whole world aggregated into 57 activities, 129 countries and 6 sectors. This database is regularly updated.

Table 3: Main databases for the GEM-E3-SI model

Data source	Data
Eurostat	Data on Slovenia and the EU countries on: ✓ Macroeconomic aggregates (GDP and its components) ✓ Technical progress (Labour productivity, Energy improvement) ✓ Energy consumption/intensity ✓ Emissions ✓ Energy production from different power technologies ✓ Sectoral information (Gross Value Added) ✓ Transport data
GTAP	✓ IO tables (Slovenia and rest of GEM-E3-SI model countries/regions) ✓ Energy balances for the rest of the world countries
IEA, World Energy Outlook 2022	✓ International fossil fuel prices ✓ Energy balances for Slovenia and the EU countries
DG ECFIN – 2021 Ageing Report	Labour market data (Employment, Population, Labour force, Unemployment rate)
ENERDATA	Emissions
TECHPOL	Capital cost of power producing technologies
UNFCCC	CO2 energy related emissions

The choice of the base year on which the model is calibrated depends on the data availability. Calibration of the model is based on the most recent year for which a fully detailed dataset is available.. The calibration of the GEM-E3-SI model makes use of EUROSTAT and GTAP. The GTAP database is used to build the SAM for Slovenia for 2014 is constructed. Then the matrix is made compatible with EUROSTAT data available for 2015 and the model is recalibrated to 2015. The calibration of dynamic relationships (like stock-flow for capital stock and investment or for financial transactions) requires data which extend beyond one single year. The IO tables for Slovenia and for the other world regions have been constructed based on the available data on the GTAP database.

The development of the GEM-E3-SI database has also made use of other data sources such as IEA (see IEA, 2022) for data on international fossil fuel prices, ENERDATA[4] and UNFCCC[5] for emission figures, TECHPOL for data on the capital costs of power producing technologies and the 2021 Ageing Report prepared by DG ECFIN on population and labour market data (see DG ECFIN, 2022).

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[3] See: https://www.gtap.agecon.purdue.edu/databases/v7/

[4] See: http://www.enerdata.net/

[5] See: http://newsroom.unfccc.int/

The elasticities used in the GEM-E3-SI model are extracted from the literature and in some cases are extracted from the GTAP database. For macroeconomic data the Eurostat database for EU countries and the World Bank database for non-EU countries have been used respectively. Data cover GDP, population, tax rates, unemployment, labor force, inflation (yearly change on Consumer Price Index) and interest rates. Capital stock data are also obtained from Eurostat for the Slovenian economy and from GTAP for the rest of other world regions. Real interest rate in GEM-E3-SI has been computed as for each region as the difference between the nominal interest rate (the yield on a 10-year government bond) minus the yearly inflation rate.

The database of the GEM-E3-SI model is available in SI_Model_Data.xlsx file found inside the GEMDAT folder (see below for detailed GEM-E3-SI files and folders structure). Sheet *INDEX* of the file summarizes all the data included in the file and presents them in format compatible with GAMS.

Calibration

In GEM-E3-SI the calibration module is written as a separate model and has a recursive structure. Calibration uses single year (base-year) data which correspond to monetary terms for which appropriate price indices are chosen so as to compute the corresponding volumes (quantities). Data for a year previous to the base year are required to give values to those variables that are lagged in the model. The calibration procedure is defined in such a manner that the model reproduces exactly the observed statistics of the base year.

A first step in the calibration of the GEM-E3-SI model is the definition of elasticities that determine all coefficients that do not correspond to directly observable variables. GEM-E3-SI uses elasticities from the literature or econometrically estimated. The types of elasticities used in the model are price, income, substitution, and trade [6].

Mathematical model formulation

GEM-E3-SI model considers all economic agents namely:

- Firms
- Household
- Government
- External sector

GEM-E3-SI model has a detailed representation of the environment while it makes provisions for links with sectoral models. The model formulation takes into consideration the micro-theory on agents' behavior and the macroeconomic relationships and flows between them. The following sections provide the mathematical formulation of the model with detailed presentation of economic agents' behavior.

Firms

Domestic activity in GEM-E3-SI is defined by product. Table 4 presents the GEM-E3-SI main sectors and the activities matched to the latter. Table 5 presents the GEM-E3-SI subsectors used in different

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[6] See Annex-II for elasticities used in GEM-E3-SI-SI

production nesting schemes. Every GEM-E3-SI activity produces a single good which is differentiated from any other good in the economy.

Table 4: GEM-E3-SI mapping of sectors to activities

Acronym	Description	GEM-E3-SI activities
prdf	Default sectors	Agriculture, Coal, Gas, Ferrous metals, Non-ferrous metals, Fabricated Metal products, Chemical Products, Basic pharmaceutical products, Rubber and plastic products, Paper products, publishing, Non-metallic minerals, Computer, electronic and optical products, Other Equipment Goods, Transport equipment (excluding EV), Consumer Goods Industries, Construction, Warehousing and support activities, Air transport, Land transport, Water transport, Market Services, Non Market Services, R&D, Biomass Solid, Biofuels, Batteries, EV Transport Equipment, Advanced Electric Appliances, Advanced Heating and Cooking Appliances, Equipment for wind power technology, Equipment for PV panels, Equipment for CCS power technology, Hydrogen, Clean Gas, CO2 Capture
pren	Energy sectors	Coal, Crude Oil, Oil, Gas, Power Supply, Biomass Solid, Biofuels, Hydrogen, Clean Gas
prtec	Power generation technologies	Coal fired, Oil fired, Gas fired, Nuclear, Biomass, Hydro electric, Wind, PV, Geothermal, CCS coal, CCS Gas, CCS Bio

Table 5: GEM-E3-SI mapping of subsectors to activities

Acronym	Description	GEM-E3-SI activities
prmane	Sectors included in the material bundle of default and resource sectors	Agriculture, Crude Oil, Ferrous metals, Non-ferrous metals, Fabricated Metal products, Chemical Products, Basic pharmaceutical products, Rubber and plastic products, Paper products, publishing, Non-metallic minerals, Computer, electronic and optical products, Other Equipment Goods, Transport equipment (excluding EV), Consumer Goods Industries, Construction, Warehousing and support activities, Air transport, Land transport, Water transport, Market Services, Non Market Services, R&D, Batteries, EV Transport Equipment, Advanced Electric Appliances, Advanced Heating and Cooking Appliances, Equipment for wind power technology, Equipment for PV panels, Equipment for CCS power technology, CO2 Capture
prma	Sectors included in the material bundle of refinery sectors	Agriculture, Ferrous metals, Non-ferrous metals, Fabricated Metal products, Chemical Products, Basic pharmaceutical products, Rubber and plastic products, Paper products, publishing, Non-metallic minerals, Computer, electronic and optical products, Other Equipment Goods, Transport equipment (excluding EV), Consumer Goods Industries, Construction, Warehousing and support activities, Air transport, Land transport, Water transport, Market Services, Non Market

		Services, R&D, Batteries, EV Transport Equipment, Advanced Electric Appliances, Advanced Heating and Cooking Appliances, Equipment for wind power technology, Equipment for PV panels, Equipment for CCS power technology, CO2 Capture
prfuel	Fuels sectors	Coal, Oil, Gas, Biomass Solid, Biofuels, Hydrogen, Clean Gas
prrs	Sectors with natural resources as main inputs	Crude Oil
prref	Refineries	Oil
pr_ele	Power supply	Power supply
prtec	Power generation technologies	Coal fired, Oil fired, Gas fired, Nuclear, Biomass, Hydro electric, Wind, PV, Geothermal, CCS coal, CCS Gas, CCS Bio

Each activity in the GEM-E3-SI is modelled by a representative firm that maximizes its profits *Π*, within a perfect competition market regime, subject to a constant elasticity of substitution (CES[7]) production function.

$$\max \Pi_i = P_i \cdot Q_i - PK_i \cdot K_i + PL_i \cdot L_i \;\; \Pi_i \qquad [1]$$

$$s.t \;\; Q_i = \bar{Q} \cdot \left(d_i^k \cdot \left(\frac{K}{\overline{K}}\right)^{\rho} + d_i^l \cdot \left(\frac{L}{\overline{L}}\right)^{\rho} \right)^{\frac{1}{\rho}} \qquad [2]$$

where:

Q: Production in volume

$\bar{Q}$: Production in volume (base year)

K: Production factor-Capital

L: Production factor-Labour

d: Share parameter

ρ: Elasticity ($\rho = \frac{\sigma-1}{\sigma}$)

σ: Elasticity of substitution

i: Activity

The solution to the above optimization problem is the following derived demand for capital and labour:

$$K_i = \overline{K}_\iota \cdot \frac{Q_i}{\overline{Q}_\iota} \cdot \left(\frac{\overline{PK_\iota} \cdot P_i}{\overline{P}_\iota \cdot PK_i} \right)^{\sigma} \qquad [3]$$

$$L_i = \overline{L}_\iota \cdot \frac{Q_i}{\overline{Q}_\iota} \cdot \left(\frac{\overline{PL_\iota} \cdot P_i}{\overline{P}_\iota \cdot PL_i} \right)^{\sigma} \qquad [4]$$

Production functions in GEM-E3-SI exhibit a nested separability scheme, involving capital (K), labour (L), energy (E) and materials (M). The activities differ in their production nesting structure. The nesting scheme differentiates among the default non-energy sectors, the sectors with natural resources inputs (coal, crude oil and natural gas extraction), electricity supply, power producing technologies and refineries. The nesting scheme differentiates among the sectors so as to take into account the specific features of each

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[7] The calibrated share form as used in Rutherford (2009) is adopted.

activity and to capture the different substitution possibilities that characterize each production sector. Below are presented the nesting structure and algebraic formulation of the different activities included in the model.

We use five occupation categories in two different bundles in labour, the “Skilled labour”, that contains the occupations technicians, clerks and managers, and the “Unskilled labour” that contains the occupations unskilled workers and shop service workers.

Electricity supply sector

The nesting scheme for the electricity supply sector is presented in Figure 2. This sector regards the electricity generation and distribution.

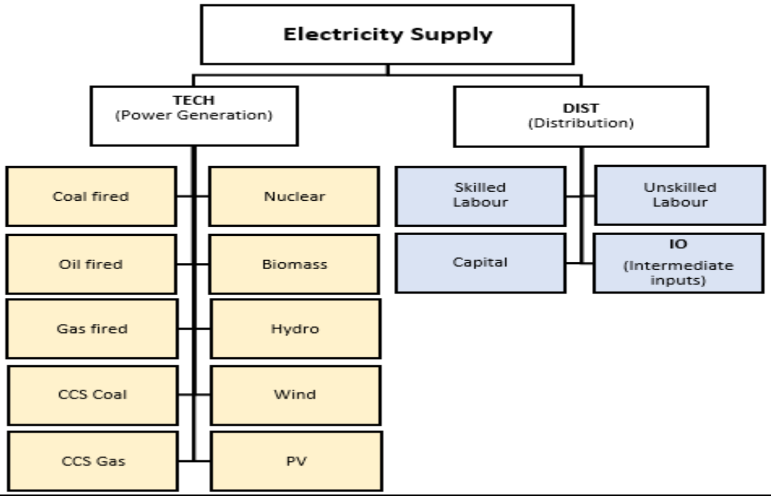
The model provides two options in calculating the power mix:

i) endogenous least cost calculation based on the firms optimization presented below

ii) calibration to exogenous power mix shares (in this option it is the share parameters of the production function that are calibrated to the exogenous market shares). This option can be based either on user exogenous assumptions or on the soft-link approach presented below.

Data on market shares can be obtained from energy balance statistics and energy focused models with detailed representation of the different power generation technologies. The shares of each technology in power generation in the base year are introduced from energy balance statistics. Some of the potential technologies that may develop in the future are not used in the base year. Hence in the model calibration provision should be made so as to introduce artificially small shares even for the non-existing technologies in order to allow for the possibility of their penetration in the future.

Figure 2: Nesting of the GEM-E3-SI model – Electricity supply



The nesting scheme develops as follows:

1st level:	XD is split into power producing technologies bundle (*TECH*) and transmission and distribution bundle (*DIST*)

$A\_XD = \mathbf{LEONTIEF}(A\_TECH, A\_DIST)$

2nd level:	TECH is split into power generation technologies in the same nest (*IO*) DIST is spit into capital, skilled and unskilled labour and intermediate input materials (*IO*).

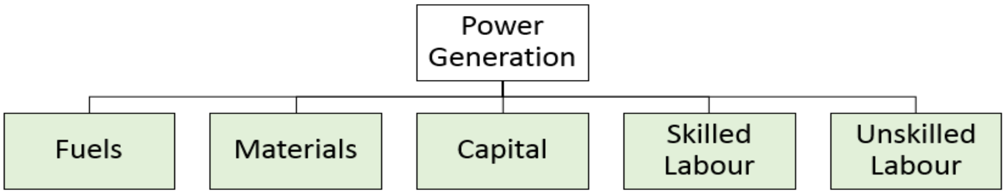
$A\_TECH = \mathbf{LEONTIEF}(A\_XD_{prtec})$ or $A\_TECH = \mathbf{WEIBULL}(A\_XD_{prtec})$ with exogenous or endogenous power mix shares, respectively

$A\_DIST = \mathbf{LEONTIEF}(A\_KAV, A\_LAV, A\_IO_{pr})$

Power producing technologies

The nesting scheme for power producing technologies is presented in Figure 3.

Figure 3: Nesting of the GEM-E3-SI model-Power producing technologies



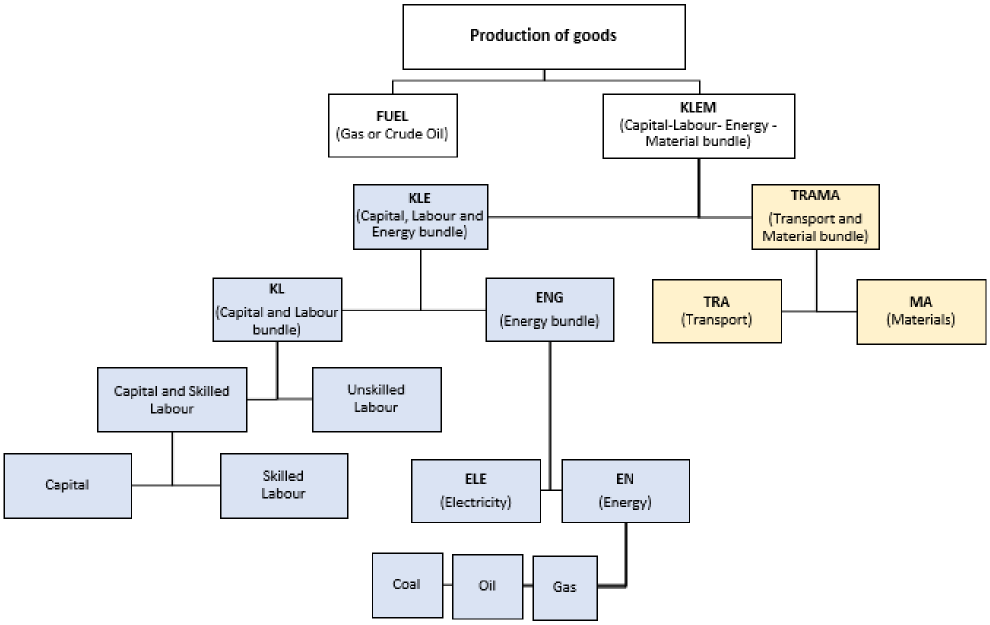
Power generation technologies exhibit a one level production function that includes capital, skilled and unskilled labour, materials and fuels.

$A\_XD = \mathbf{LEONTIEF}(A\_KAV, A\_LAV, A\_IO)$

Refineries

Figure 4 presents the nesting scheme of the refineries sector. The nesting structure is similar to the default sectors with a change at the top level of the nest where the two aggregates are now *KLEM* and fuels (*FUEL*).

Figure 4: Nesting of the GEM-E3-SI model – Refineries



The nesting scheme develops as follows:

1st level:	XD is split into capital, labour, energy and material bundle (*KLEM*) and fuels (*IO*)

$$XD = a\_xd_0 \cdot \left(d^{klem} \cdot \left(\frac{A\_KLEM}{a\_klem_0}\right)^{\rho} + d^{io} \cdot \left(\frac{A\_IO_{Crude\_Oil}}{a\_io_0}\right)^{\rho} + d^{io} \cdot \left(\frac{A\_IO_{Gas}}{a\_io_0}\right)^{\rho}\right)^{\frac{1}{\rho}}$$

2nd level:	KLEM is split into capital, labour and energy bundle (*KLE*) and transport and material bundle (*TRAMA*)

$$A\_KLEM = \mathbf{CES}(A\_KLE, A\_TRAMA)$$

3rd level:	KLE is split into capital and labour bundle (*KL*) and energy bundle (*ENG*) TRAMA is split into transport (TRANS) and materials bundle (*MA*)

$$A\_KLE = \mathbf{CES}(A\_KL, A\_ENG)$$
$$A\_TRAMA = \mathbf{LEONTIEF}(A\_TRANS, A\_MA)$$

4th level:	KL is split into capital and skilled labour bundle (KLSKLD) and unskilled labour ENG is split into fuels energy bundle (EN) and electricity (ELE) TRANS is split into land transport (TRALAND), water transport (TRAWATER) and air transport (TRAAIR) MA is split into intermediate inputs materials (IO)

$$A\_KL = \mathbf{CES}(A\_KLSKLD, A\_LAV\_UNSKLD\ )$$
$$A\_ENG = \mathbf{CES}(A\_EN, A\_ELE)$$
$$A\_TRANS = \mathbf{CES}(A\_TRALAND, A\_TRAWATER, A\_TRAAIR)$$
$$A\_MA = \mathbf{CES}\left(A\_IO_{prma}\right)$$

5th level:	KLSKLD is split into capital and skilled labour EN is split into fuels energy intermediate inputs (IO) ELE is equal to electricity intermediate inputs (IO)

$$A\_KLSKLD = \mathbf{CES}(A\_KAV, A\_LAV\_SKLD)$$
$$A\_EN = \mathbf{CES}\left(A\_IO_{prfuel}\right)$$
$$A\_ELE = A\_IO_{prele}$$

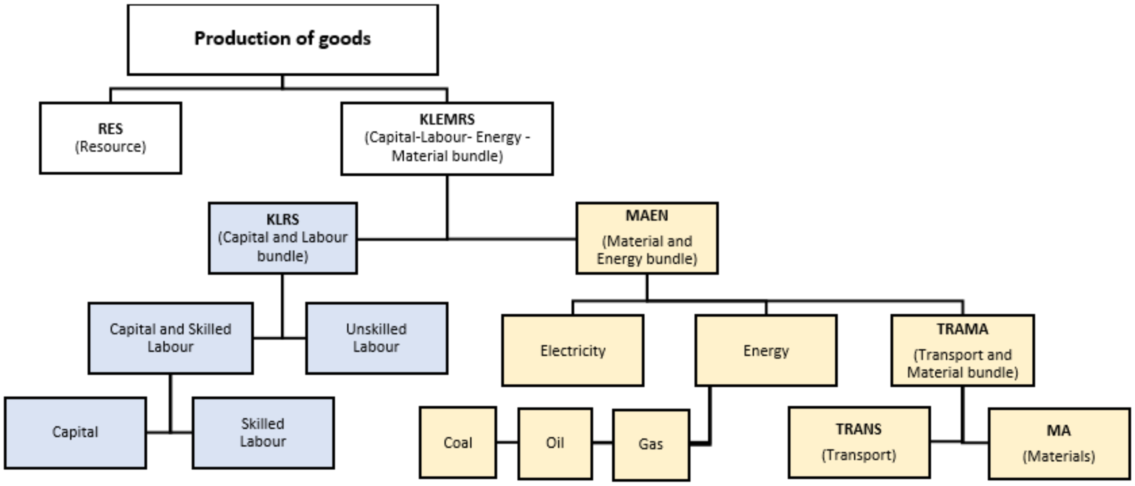
6th level:	TRALAND is equal to land transport intermediate input (IO) TRAAIR is equal to air transport intermediate input (IO) TRAWATER is equal to water transport intermediate input (IO)

$$A\_TRALAND = A\_IO_{land}$$
$$A\_TRAAIR = A\_IO_{air}$$
$$A\_TRAWATER = A\_IO_{water}$$

Resource sectors

The nesting scheme for the resource sectors in presented in Figure 5.

Figure 5: Nesting of GEM-E3-SI model – Resource sectors



The nesting scheme develops as follows:

1st level:	XD is split into capital, labour, energy and material bundle (*KLEMRS*) and resources (*RES*)

$$A\_XD = a\_xd_0 \cdot \left(d^{klem} \cdot \left(\frac{A\_KLEMRS}{a\_klemrs_0}\right)^{\rho} + d^{res} \cdot \left(\frac{A\_RES}{a\_res_0}\right)^{\rho}\right)^{\frac{1}{\rho}}$$

2nd level:	KLEMRS is split into capital and labour bundle (*KLRS*) and material and energy bundle (*MAEN*) RES is equal to resources

$A\_KLEM = \mathbf{CES}(A\_KLRS, A\_MAEN)$
$A\_RES = \text{Resources}$

3rd level:	KLRS is split into capital and skilled labour bundle (KLRSSKLD) and unskilled labour MAEN is split into fuels energy bundle (EN), electricity (ELE) and transport – material bundle (TRAMA)

$A\_KLRS = \mathbf{CES}(A\_KLRSSKLD, A\_LAV\_UNSKLD)$
$A\_MAEN = \mathbf{CES}(A\_EN, A\_ELE, A\_TRAMA)$

4th level:	KLRSSKLD is split into capital and skilled labour EN is split into fuels energy intermediate inputs (IO) ELE is equal to electricity intermediate inputs (IO) TRAMA is split into transport (TRANS) and materials bundle (*MA*)

$A\_KLRSSKLD = \mathbf{CES}(A\_KAV, A\_LAV\_SKLD)$
$A\_EN = \mathbf{CES}(A\_IO_{prfuel})$
$A\_ELE = A\_IO_{prele}$
$A\_TRAMA = \mathbf{LEONTIEF}(A\_TRANS, A\_MA)$

5th level:	TRANS is split into land transport (TRALAND), water transport (TRAWATER) and air transport (TRAAIR) MA is split into intermediate inputs materials (IO)

$A\_TRANS = \mathbf{CES}(A\_TRALAND, A\_TRAWATER, A\_TRAAIR)$
$A\_MA = \mathbf{CES}(A\_IO_{prmane})$

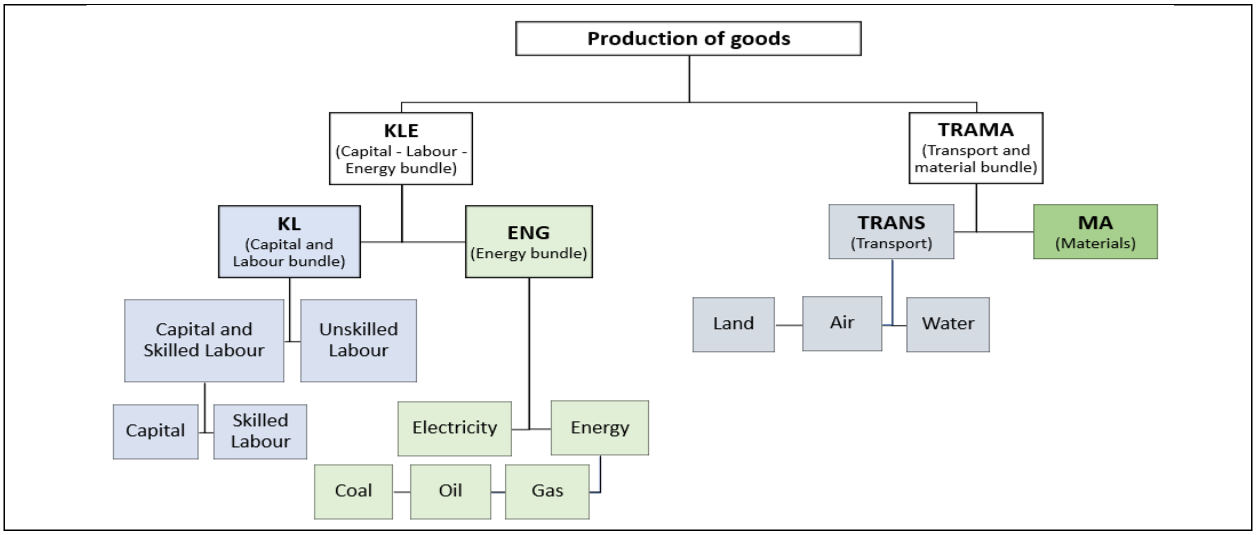
6th level:	TRALAND is equal to land transport intermediate input (IO) TRAAIR is equal to air transport intermediate input (IO) TRAWATER is equal to water transport intermediate input (IO)

$A\_TRALAND = A\_IO_{land}$
$A\_TRAAIR = A\_IO_{air}$
$A\_TRAWATER = A\_IO_{water}$

Default sectors

The nesting scheme for the default non-energy sectors is presented in Figure 6Figure 6.

Figure 6: Nesting of GEM-E3-SI default sectors



The nesting scheme develops as follows:

1st level:	XD is split into capital, labour, energy bundle (*KLE*) and transport and materials bundle (*TRAMA*)

$$A\_XD = a\_xd_0 \cdot \left(d^{kle} \cdot \left(\frac{A\_KLE}{a\_kle_0}\right)^{\rho} + d^{trama} \cdot \left(\frac{A\_TRAMA}{a\_trama_0}\right)^{\rho} \right)^{\frac{1}{\rho}}$$

where: d: share parameter and ρ: substitution elasticity parameter

2nd level:	KLE is split into capital and labour bundle (*KL*) and energy bundle (*ENG*) TRAMA is split into transport (TRANS) and materials bundle (*MA*)

$$A\_KLE = \mathbf{CES}(A\_KL, A\_ENG)$$
$$A\_TRAMA = \mathbf{LEONTIEF}(A\_TRANS, A\_MA)$$

3rd level:	KL is split into capital and skilled labour bundle (KLSKLD) and unskilled labour ENG is split into fuels energy bundle (EN) and electricity (ELE) TRANS is split into land transport (TRALAND), water transport (TRAWATER) and air transport (TRAAIR) MA is split into intermediate inputs materials (IO)

$$A\_KL = \mathbf{CES}(A\_KLSKLD, A\_LAV\_UNSKLD\ )$$
$$A\_ENG = \mathbf{CES}(A\_EN, A\_ELE)$$
$$A\_TRANS = \mathbf{CES}(A\_TRALAND, A\_TRAWATER, A\_TRAAIR)$$
$$A\_MA = \mathbf{CES}\left(A\_IO_{prmane}\right)$$

4th level:	KLSKLD is split into capital and skilled labour EN is split into fuels energy intermediate inputs (IO) ELE is equal to electricity intermediate inputs (IO) TRALAND is equal to land transport intermediate input (IO) TRAAIR is equal to air transport intermediate input (IO) TRAWATER is equal to water transport intermediate input (IO)

$$A\_KLSKLD = \mathbf{CES}(A\_KAV, A\_LAV\_SKLD)$$
$$A\_EN = \mathbf{CES}\left(A\_IO_{prfuel}\right)$$
$$A\_ELE = A\_IO_{prele}$$
$$A\_TRALAND = A\_IO_{land}$$
$$A\_TRAAIR = A\_IO_{air}$$
$$A\_TRAWATER = A\_IO_{water}$$

Investment

GEM-E3-SI is a recursive dynamic model solved sequentially over time. It is assumed that investment that takes place in time *t* increases the production capacity in the following period at time *t+1*. The law of motion of capital stock and investment are given by:

$$A\_KAVC_{pr,er,t} = \left(1 - d_{pr,er,t}\right) \cdot A\_KAVC_{pr,er,t-1} + A\_INV_{pr,er,t} \qquad [5]$$

$$A\_INV_{pr,er,t} = A\_KAV^{*}_{pr,er,t} \cdot \left[\frac{P\_KAV_{pr,er,t}}{P\_INV_{pr,er,t} \cdot (rr_{er,t} + d_{pr,er,t})} - 1 + d_{pr,er,t} + stgr_{pr,er,t}\right] \qquad [6]$$

where:

$A\_KAVC_{pr,er,t}$: capital stock of firms

$d_{pr,er,t}$: depreciation rate

$A\_INV_{pr,er,t}$: investment of firms in volume

$P\_KAV_{pr,er,t}$: the user cost of capital

$P\_INV_{pr,er,t}$: the price of investment

$stgr_{pr,er,t}$: the exogenously specified expected growth rate of the sector

rr: interest rate

pr, er: activity sector

t: time

Firm's investment is translated into demand for investment goods which are produced from the rest of the sectors of the economy through an investment matrix of constant coefficients $tinvpv_{pr,br}$:

$$A\_INVP_{pr,br,er,t} = tinvpv_{pr,br,er,t} \cdot \frac{p\_inv0_{br.er}}{p\_invp0_{pr.er}} \cdot A\_INV_{pr,er,t} \qquad [7]$$

where:

$tinvpv_{pr,br,er,t}$: share of each firm in delivery of investment

$A\_INVP_{pr,br,er,t}$: deliveries for investment by activity

p_inv0: Base year price of Investment (unit cost of investment for the firm)

p_invp0: Base year price of investment product

br, pr, er: activity sectors

Household

For each region/country in the GEM-E3-SI model there exists a representative household that maximizes its utility function subject to its budget constraint. Its budget is derived from: i) labour supply, ii) dividends from firm's ownership iii) transfers from other institutional sectors

Its utility function is a Linear Expenditure System (LES[8]) function:

$$U(CV) = \big(ln(CV - CH)\big) \qquad [8]$$

Where *CV* is total consumption, *CH* is the subsistence minima consumption. Total and disposable income is derived as follows:

$$M = PL \cdot L + W^{oth} \qquad [9]$$

$$YDISP = M - S \qquad [10]$$

where:

$PL \cdot L$: labour income

W^{oth}: non-labour income (e.g. dividends, social transfers)

S: Savings

The consumer's optimization problem is defined as:

$$max_{CV} \int_{t=0}^{\infty} e^{-stp \cdot t} U(CV) \qquad [11]$$

$$s.t.\ \dot{w}(t) = YDISP(t) - PCI(t) \cdot CV(t) - PCI(t) \cdot CH(t) \qquad [12]$$

where *stp* is the social time preference / subjective rate of discount. Solving the above problem the optimal demand for total consumption is derived:

$$CV = \mathrm{CH} + \mu \cdot \frac{bh}{PCI} \cdot (YDISP - PCI \cdot CH) \qquad [13]$$

---

[8] See Stone (1954)

μ is a proxy to the marginal propensity to consume $\mu = \frac{stp}{r}$, and *r* is the interest rate. *bh* is the LES private consumption share parameter. Once the household decides total household consumption it needs to decide over the different consumption categories (*FN*).

GEM-E3-SI uses consumption matrices that translate consumption by purpose to specific demand for consumption by product. Hence the final household demand by product is calculated as:

$$A\_HC_{pr} = \sum_{\mathrm{fn}} tchcfv_{pr,fn} \cdot \mathrm{A\_HCFV_{fn}} \qquad [14]$$

where

$tchcfv_{pr,fn}$: private consumption coefficients

$\mathrm{A\_HCFV_{fn}}$: consumption by purpose in volume

A_HC_{pr}: consumption by branch in volume

fn: production categories

Government

Government's behaviour is exogenous to the GEM-E3-SI model. Government's final demand by product (A_$GC_{pr,er,t}$) is obtained by applying fixed coefficients ($tgcv_{pr,er,t}$) to the exogenous volume of government consumption ($\mathrm{gctv}_{er,t}$):

$$A\_GC_{pr,er,t} = gctv_{er,t} \cdot tgcv_{pr,er,t}\ , if\ swGC = 0 \qquad [15]$$

$$A\_GC_{pr,er,t} = f(GDP)\ , if\ swGC = 1 \qquad [16]$$

$swGC$ is the switch for the endogenous/exogenous calculation of government consumption (see below for details on the switches included in the GEM-E3-SI model). In the case where swGC = 1 the government consumption is a constant share of GDP.

The following equation describes all tax revenues and subsidy expenditure of the government disaggregated by government tax/revenue categories:

$$V\_FGRB_{gvb,pr,er,t} = \sum_{cr} txduto_{pr,er,cr,t} \cdot A\_IMPO_{pr,er,cr,t} \cdot \frac{WPI_t}{WPI_0} \qquad GVB\text{=duties} \qquad [17]$$

$$\begin{aligned} V\_FGRB_{gvb,pr,er,t} = {} & txsub_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_XD_{pr,er,t} \\ & + \sum_{fn} txsubnrj\_HC_{pr,fn,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_HCFVPV_{pr,fn,er,t} \\ & + \sum_{br} txsubnrj\_Firms_{pr,br,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_IO_{pr,br,er,t} \end{aligned} \qquad GVB\text{=subsidies} \qquad [18]$$

$$\begin{aligned} V\_FGRB_{gvb,pr,er,t} = {} & txit_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} \\ & \cdot \left[\sum_{br} \left(A\_IO_{pr,br,er,t} + ABIOV_{pr,br,er,t} \right) + A\_GC_{pr,er,t} + A\_HC_{pr,er,t} \right. \\ & + \sum_{br} \left(A\_INVP_{pr,br,er,t} \right) + A\_BUILD\_ENERGYSAVE\_H_{pr,er,t} \\ & \left. + A\_BUILD\_ENERGYSAVE\_F_{pr,er,t} \right] \\ & + \sum_{fn} txitnrj\_HC_{pr,fn,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_HCFVPV_{pr,fn,er,t} \\ & + \sum_{br} txitnrj\_Firms_{pr,br,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_IO_{pr,br,er,t} \end{aligned}$$

GVB=Indirect taxes [19]

$$V\_FGRB_{gvb,pr,er,t} = txvat_{pr,er,t} \cdot \left(P\_Y_{pr,er,t} + txit_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_HC_{pr,er,t} \right)$$

GVB=Value added tax [20]

$$\begin{aligned} V\_FGRB_{gvb,pr,er,t} = {} & \sum_{ghga} \left(TXENV_{ghga,pr,er,t} \cdot EMMBR_{ghga,pr,er,t} \right) \\ & - \sum_{ghga} \left(\left(1 - SHAUCTBR_{ghga,pr,er,t} \right) \cdot SALEP_{ghga,pr,er,t} \right) \\ & + \sum_{ghga,fn} \left(TXENVHDG_{ghga,fn,er,t} \cdot bech_{ghga,pr,fn,er,t} \cdot aerh_{pr,fn,er,t} \right. \\ & \left. \cdot\, eafh_{pr,fn,er,t} \cdot A\_HCFVPV_{pr,fn,er,t} \right) \end{aligned}$$

GVB= Environmental tax [21]

where:

$txduto_{pr,er,cr,t}$: bilateral duty rate

$txsub_{pr,er,t}$: the subsidy rate

$txsubnrj\_HC_{pr,fn,er,t}$: the subsidy rate related to energy for household

$txsubnrj\_Firms_{pr,br,er,t}$: the subsidy rate related to energy for firms

$txit_{pr,er,t}$: the indirect tax rate

$txitnrj\_HC_{pr,fn,er,t}$: the energy tax rate imposed on household

$txitnrj\_Firms_{pr,br,er,t}$: the energy tax rate imposed on firms

$txvat_{pr,er,t}$: VAT rate per branch

$TXENV_{pr,er,t}$: the environmental tax for firms

$P\_Y_{pr,er,t}$: the price of domestic demand

$A\_IMPO_{pr,er,cr,t}$: imports in volume

$A\_XD_{pr,er,t}$: production in volume

$A\_IO_{pr,br,er,t}$: IO deliveries between sectors of activities

$ABIOV_{pr,br,er,t}$: deliveries of products for abatement

$A\_HC_{pr,er,t}$: the deliveries to private consumption

$A\_GC_{pr,er,t}$: deliveries to public consumption by branches

$A\_BUILD\_ENERGYSAVE\_H_{pr,er,t}$: Building materials for energy saving in Households

$A\_BUILD\_ENERGYSAVE\_F_{pr,er,t}$: Building materials for energy saving in Firms

$P\_INVP_{pr,er,t}$: the price of deliveries to investment

$A\_EMMBR_{ghga,pr,er,t}$: the emissions by branches

$shauctbr_{ghga,pr,er,t}$: the share of auctioned permits

$SALEP_{ghga,pr,er,t}$: the value of endowment in permits

WPI_t: the world price index

WPI_0: the world price index in the base year

$TXENVHDG_{ghga,dg,er,t}$: the environmental tax for household

$bech_{ghga,pr,fn,er,t}$: the emission factor

$aerh_{pr,fn,er,t}$: the share of energy combusted to total energy consumed

$eafh_{pr,fn,er,t}$: the emission adjustment factor

External sector

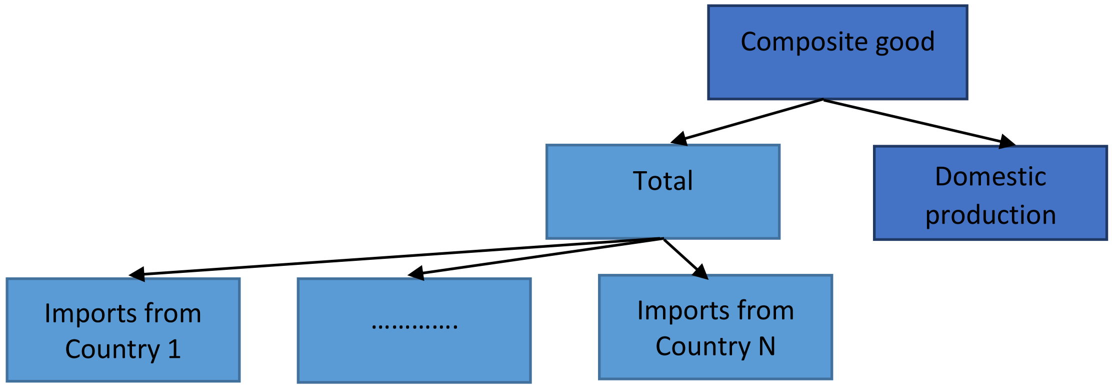
Firms and households consume a composite good that is composed of an imported part and a domestically produced part. Imported and domestically produced goods are considered as imperfect substitutes (Armington, 1979).

The supply decision of a good in the domestic economy is split in two stages:

1. At the first stage firms decide on the overall imports that they require.
2. At the second stage firms decide from which countries they will import. They split total import demand decided at stage 1 to regional/country demand.

Each country buys and imports at the prices set by the supplying countries following their export supply behavior.

Figure 7: Trade decision tree



Firms' cost minimization problem (for the Imports 1st level) is:

$$\min C_{pr,er,t} = P\_XD_{pr,er,t} \cdot A\_XXD_{pr,er,t} + P\_IMP_{pr,er,t} \cdot A\_IMP_{pr,er,t} \qquad [22]$$

where:

$P\_XD_{pr,er,t}$: price of domestically produced good

$A\_XXD_{pr,er,t}$: production for domestic use

$P\_IMP_{pr,er,t}$: import price

$A\_IMP_{pr,er,t}$: imports

such that:

$$A\_Y_{pr,er,t} = AC_{pr,er,t} \cdot \left[\delta_{pr,er,t} \cdot A\_XXD_{pr,er,t}^{\frac{\sigma_{x_{pr,er,t}}-1}{\sigma_{x_{pr,er,t}}}} + \left(1-\delta_{pr,er,t}\right) \cdot A\_IMP_{pr,er,t}^{\frac{\sigma_{x_{pr,er,t}}-1}{\sigma_{x_{pr,er,t}}}}\right]^{\frac{\sigma_{x_{pr,er,t}}}{\sigma_{x_{pr,er,t}}-1}} \quad [23]$$

where:

$A\_Y_{pr,er,t}$: composite good

$AC_{pr,er,t}$: scale parameter in the Armington function

$\delta_{pr,er,t}$: share parameter estimated from the base year data related to the value shares of $A\_XXD_{pr,er,t}$ and $A\_IMP_{pr,er,t}$ in the demand for composite good $Y_{pr,er,t}$

σ_{χ}: the Armington elasticity between imported and domestically produced goods

The optimal demand for domestic and imported goods is obtained by employing the Shephard's lemma.

$$\mathrm{A\_XXD_{pr,er,t}} = \begin{cases} \mathrm{A\_Y_{pr,er,t}} \cdot \mathrm{AC_{pr,er,t}^{\sigma_{x_{pr,er,t}}-1}} \cdot \left(1-\delta_{\mathrm{pr,er,t}}\right)^{\sigma_{x_{\mathrm{pr,er,t}}}} \cdot \left(\dfrac{\mathrm{P\_Y_{pr,er,t}}}{\mathrm{P\_XD_{pr,er,t}}}\right)^{\sigma_{x_{\mathrm{pr,er,t}}}} & \text{if } \mathrm{AC_{pr,er,t}} \neq 0 \\ \mathrm{A\_Y_{pr,er,t}} & \text{if } \mathrm{AC_{pr,er,t}} = 0 \end{cases} \quad [24]$$

$$A\_IMPC_{pr,er,t} = A\_Y_{pr,er,t} \cdot AC_{pr,er,t}^{\sigma_{x_{pr,er,t}}-1} \cdot \delta_{pr,er,t}^{\sigma_{x,pr,er,t}} \cdot \left(\frac{P\_Y_{pr,er,t}}{P\_IMP_{pr,er,t}}\right)^{\sigma_{x_{pr,er,t}}} \quad [25]$$

where:

$A\_IMPC_{pr,er,t}$: the competitive imports by branch

$P\_Y_{pr,er,t}$: the unit cost for the composite good

$$P\_Y_{pr,er,t} = \frac{1}{AC_{pr,er,t}} \cdot \left[\delta_{pr,er,t}^{\sigma_{x,pr,er,t}} \cdot P\_IMP_{pr,er,t}^{1-\sigma_{x_{pr,er,t}}} \cdot + \left(1-\delta_{pr,er,t}\right)^{\sigma_{x_{pr,eu,t}}} \cdot P\_XD_{pr,er,t}^{1-\sigma_{x_{pr,er,t}}}\right]^{\frac{1}{1-\sigma_{x_{pr,er,t}}}} \quad if\ pr = brt \quad [26]$$

$$P\_Y_{pr,er,t} = P\_IMP_{pr,er,t} \cdot rtxd_{pr,er,t} + P\_PD_{pr,er,t} \cdot txsub_{pr,er,t} \frac{WPI_t}{WPI_0} \cdot \left(1 - rtxd_{pr,er,t}\right) \quad if\ pr = brnt \quad [27]$$

$$A\_IMP_{pr,er,t} = A\_IMPC_{pr,er,t} + A\_IMPNC_{pr,er,t} \quad if\ pr = brt \quad [28]$$

$$A\_IMPNC_{pr,er,t} = rtnc_{pr,er,t} \cdot A\_XD_{pr,er,t} \quad [29]$$

$$A\_IMP_{pr,er,t} = rtxd_{pr,er,t} \cdot A\_Y_{pr,er,t} \quad if\ pr = brnt \quad [30]$$

$$P\_IMP_{pr,er,t} = \left[\sum_{cr} beta_{pr,er,cr,t}^{sigmai_{pr,er,t}} \cdot P\_IMPO_{pr,er,cr,t}{}^{(1-sigmai_{pr,er,t})}\right]^{\left(\frac{1}{1-sigmai_{pr,er,t}}\right)} \quad [31]$$

where:

$rtnc_{pr,er,t}$: is the share of non-competitive imports

$P\_IMP_{pr,er,t}$: price of total imports

$beta_{pr,er,cr,t}$: share parameter

$\sigma_{pr,er,t}$: the elasticity of substitution

$P\_IMPO_{pr,er,cr,t}$: import price of good *pr* for country *er* originating from country *cr*

$$P\_IMPO_{pr,cs,cr,t} = P\_PWE_{pr,cr,t} + txduto_{pr,cs,cr,t} \cdot \frac{WPI_t}{WPI_0} + \sum_{itrn} (cif\_vtwr_{itrn,pr,cs,t} \cdot P\_TR_{itrn,t}) \qquad [32]$$

where:

$P\_PWE_{pr,cr,t}$: the export price in international currency

$cif\_vtwr_{,itrn,pr,cs,t}$: the demand share for transport margins

$P\_TR_{itrn,t,}$: the international transport margin price

2.1.1.1 International transport services

The GTAP database identifies two sets of data as regards to trade:

1. bilateral trade flows of goods and services (the representation of which in the GEM-E3-SI model is described in the previous section)
2. supply of international trade margins (i.e. freight transport services)

The GTAP parameters related to trade are:

Name	Description
VST(mg*,er)	Margin exports
VTWR(mg,pr,er,cr)	Margin usage in facilitation of flow of commodity pr from er to cr

* mg: air, land, water, Source: McDougal (2006)

The sector that supplies the international transport services (i.e. water, air and land transport) earns the difference between *c.i.f.* and *f.o.b.* ($\sum_r VST_{j,r}$, the supply of margins). The market clearance conditions for the international market services imply that the sum across all regions of service exports equals the sum of all bilateral trade flows of service inputs (usage).

$$\sum_r vst_{j,r} = \sum_{i,r,s} vtwr_{j,i,r,s} \qquad [33]$$

In the GEM-E3-SI model the international transport margin price is determined by the following equation:

$$P\_TR_{itrn,t} \leq \sum_{er} \left(thetavst_{itrn,er,t} \cdot \frac{P\_PWE_{pr,er,t}}{P\_PWE_{pr,er,0}} \right) \qquad [34]$$

where:

$thetavst_{itrn,er,t}$: measures the share of each country in total international transport margins in the base year. The activity level of each type of transport is defined as:

$$A\_YVST_{itrn,t} \cdot vtag_{itrn,t} \geq \sum_{br,er,cr} (A\_EXPO_{pr,er,cr,t} \cdot cif\_vtwr_{itrn,pr,er,cs,t}) \qquad [35]$$

$vtag_{itrn,t}$: the output per type of transport in the international pool in the base year

Exports of transport services are given by:

$$A\_YVTWR_{itrn,er,t} = A\_YVST_{itrn,t} \cdot vtag_{itrn,t} \cdot thetavst_{itrn,er,t} \qquad [36]$$

The bilateral import price equals the export price of the exporter in case of tradable services, while in the case of merchandise sectors the bilateral import price is given by the export price plus the bilateral *cif/fob* margins.

$A\_IMPO_{br,cr,cs,t}$: denotes imports of good *pr* demanded by country *cr* from country *cs*.

$$A\_IMPO_{br,cr,cs,t=}A\_IMP_{nr,cr,t}\cdot\left(beta_{br,cr,cs,t}\cdot\frac{P\_IMP_{br,cr,t}}{P\_IMPO_{br,cr,cs,t}}\right)^{sigmai_{br,cr,t}} \qquad [37]$$

Institutional transfers

The institutional sectors included in the GEM-E3-SI model are:

- Households (*h*)
- Firms (*f*)
- Government (*g*)
- World (*w*)

An example of different type of transactions amongst the different agents is presented in tabular form in Table 6, where rows represent revenues and columns represent expenditures of the institutional sectors.

Table 6: Institutional sector transfers

		Expenditures			
		Household	**Firms**	**Government**	**World**
Revenues	**Household**		Dividends	Social Benefits	Remittances
	Firms			Subsidies	
	Government	Direct Taxes Social Security	Direct Taxes		
	World	Transfers abroad			

The transfers between sectors are described by the following equations in GEM-E3-SI model.

$$V\_FSESE_{se,sr,er,t} = txdividh_{er,t}\cdot\sum_{fa=CAP} V\_FSEFA_{se,fa,er,t}$$

Firms pay / households receive (*se=h*), (*sr=f*), (*fa=CAP*) [38]

$$V\_FSESE_{se,sr,er,t} = V\_FGRS_{"SS","F",er,t} + V\_FGRS_{"SS",sr,er,t} + V\_FGRS_{"DT",sr,er,t}$$

Household pay / Government receive (*se=g*), (*sr=h*) [39]

$$V\_FSESE_{se,sr,er,t} = V\_FGRS_{"DT",sr,er,t} + txdividh_{er,t}\cdot\sum_{fa=CAP} V\_FSEFA_{se,sr,er,t}$$

Firms pay / Government receive (*se=g*), (*sr=f*) [40]

$$\begin{aligned} V\_FSESE_{se,sr,er,t} &= Social\_Benefit_{er,t}\cdot actpt_{er,t}\cdot\frac{WPI_t}{WPI_0} \\ &+ \sum_{ghga}\sum_{fn}\left(1 - SHAUCTH_{ghga,er,t}\right)\cdot SALEPH_{ghga,fn,er,t} \\ &+ Property\_Income_{se,er}\cdot\frac{WPI_t}{WPI_0} \end{aligned}$$

Government pays/ households receive (*se=h*), (*sr=g*) [41]

$$V\_FSESE_{se,sr,er,t} = \sum_{ghga}\sum_{br} BUSAT_{ghga,br,er,t} + \sum_{po1}\sum_{lnd} BUSATH_{ghga,fn,er,t}$$

Government pays / World receives [42]

(*se=w*), (*sr=g*)

$$V\_FGRS_{gvs,se,er,t} = \sum_{br} \left(txhss_{br,er,t} \left(1 - txfss_{br,er,t} \right) \cdot V\_VA_{fa,br,er,t} \right)$$

Household pays social security (*gvs=ss*), (*se=h*), (*fa=LAB*) [43]

$$V\_FGRS_{gvs,se,er,t} = \sum_{br} \left(txfss_{br,er,t} \cdot V\_VA_{fa,br,er,t} \right)$$

Firms pays social security (*gvs=ss*), (*se=f*), (*fa=LAB*) [44]

$$\begin{aligned} V\_FGRS_{gvs,se,er,t} &= txdirtaxf_{er,t} \\ &\cdot \left(\sum_{fa} V\_FSEFA_{se,fa,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t} \right) \end{aligned}$$

Firm pays direct taxes (*gvs=dt*), (*se=f*) [45]

$$\begin{aligned} V\_FGRS_{gvs,se,er,t} &= txdirtaxh_{er,t} \\ &\cdot \left(\sum_{fa} V\_FSEFA_{se,fa,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t} \right) \end{aligned}$$

Household pays direct taxes (*gvs=dt*), (*se=h*) [46]

where:

se, sr: institutional sectors, i.e. households (*h*), firms (*f*), government (*g*), and world (*w*).

$txdividh_{er,t}$: the rate of dividend from firms to household

$V\_FSEFA_{se,sr,er,t}$: the payments by factors to the sectors

$V\_FSESE_{se,sr,er,t}$: the transfers between sectors

$Social\_Benefit_{er,t}$: social benefits rate

$actp\_t_{er,t}$: the active population

$SHAUCTH_{po1,er,t}$: the share of auctioned permits per household

$SALEPH_{po1,lnd,er,t}$: the value of endowment of permits for households

$SALEP_{po1,er,t}$: the value of endowment of permits for firms

$BUSAT_{po1,br,er,t}$: the expenditure of firms for buying permits

$BUSATH_{po1,br,er,t}$: the expenditure of households for buying permits

$V\_FGRS_{gvs,se,er,t}$: the payments by sectors to public sector expenditure categories

$txfss_{br,er,t}$: the social security rate on firms

$txhss_{br,er,t}$: the social security rate on households

$txdirtaxf_{er,t}$: the rate of direct taxes on firms

$txdirtaxh_{er,t}$: the rate of direct taxes on household

The transfers between factors of production and the economic sectors as given in the Social Accounting Matrix (SAM) are described in the equations below. The most important of these transfers include:

$$V\_VA_{fa,pr,er,t} = \sum_{sk\_type} A\_LAV_{sk\_type,pr,er,t} \cdot P\_LAV_{sk\_type,pr,er,t}$$

Value added from labour factor (*fa=sk_type*) [47]

$$V\_VA_{fa,pr,er,t} = A\_KAV_{pr,er,t} \cdot P\_KAV_{pr,er,t} + \sum_{ghga} \left(\left(1 - SHAUCTBR_{ghga,pr,er,t} \right) \right) \cdot SALEP_{ghga,pr,er,t}$$

Value added from capital factor (*fa*=*k*) [48]

$$V\_VA_{fa,pr,er,t} = A\_RESFV_{pr,er,t} \cdot P\_RESF_{pr,er,t}$$

Value added from resources factor (*fa*=*r*) [49]

$$V\_FSEFAT_{fa,pr,er,t} = \sum_{br} V\_VA_{fa,br,er,t}$$

Total payment of factors (*fa=l, k, r*) [50]

$$V\_FSEFA_{se,fa,er,t} = txfsefa_{se,fa,er,t} \cdot \sum_{br} V\_VA_{fa,br,er,t}$$

Factor payments to government (*se*=*g*) [51]

where:

$V\_VA_{fa,pr.er,t}$: the value added

$A\_LAV_{sk\_type,br,er,t}$: the demand for labour

$P\_LAV_{sk\_type,br,er,t}$: the unit cost of labour

$txfsefa_{se,fa,er,t}$: the parameter indicating the share of the each agent to factor income (as calculated in base year)

$A\_KAV_{pr,er,t}$: the capital stock

$P\_KAV_{pr,er,\mathrm{t}}$: the user cost of capital

$A\_RESFV_{pr,er,t}$: volume of reserves

$P\_RESF_{pr,er,t}$: price of reserves

$V\_FSEFAT_{fa,pr,er,t}$: the total payments by factors

$V\_FSEFA_{se,fa,pr,er,t}$: payment by factor to sectors

$SHAUCTBR_{ghga,pr,er,t}$: share of auctioned permits per household

The final consumption of the sectors of the economy is given in equations below:

$$V\_FC_{se,er,t} = V\_HCDTOT_{er,t}$$

se=h [52]

$$V\_FC_{se,er,t} = 0$$

se=f [53]

$$V\_FC_{se,er,t} = \sum_{pr} P\_GC_{pr,er,t} \cdot A\_GC_{pr,er,t}$$

se=g [54]

$$V\_FC_{se,er,t} = \sum_{pr} \left(P\_PWE_{pr,er,t} \cdot \sum_{eu} A\_EXPO_{pr,er,eu,t} + P\_PWE_{pr,er,t} \cdot A\_YVTWR_{pr,er,t} \right)$$

se=w [55]

where:

$V\_FC_{se,er,t}$: the consumption by sector

$V\_HCDTOT_{er,t}$: private consumption in value

$P\_PWE_{pr,er,\mathrm{t}}$: the unit cost of exports

$A\_EXPO_{pr,er,cr,t}$: the bilateral exports in volume

$A\_YVTWR_{pr,er,t}$: the exports to international transport pool in volume

A_GC$_{pr,er,t}$: the government consumption in volume.

P_GC$_{pr,er,t}$: the price of delivery to domestic consumption.

The savings of each agent is determined by:

$$V\_SAVE_{se,er,t} = V\_YDISP_{er,t} - V\_HCDTOT_{er,t} \qquad se{=}h \qquad [56]$$

$$V\_SAVE_{se,er,t} = \sum_{fa} V\_FSEFA_{se,sr,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t} - V\_FC_{se,er,t} - \sum_{sr} V\_FSESE_{sr,se,er,t} \qquad se{=}f \qquad [57]$$

$$V\_SAVE_{se,er,t} = \sum_{gv}\sum_{br} V\_FGRB_{gv,br,er,t} + \sum_{fa} V\_FSEFA_{se,sr,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t} - V\_FC_{se,er,t} - \sum_{sr} V\_FSESE_{sr,se,er,t} \qquad se{=}g \qquad [58]$$

$$V\_SAVE_{se,er,t} = \sum_{pr}\sum_{cr} P\_IMPO_{pr,er,cr,t} \cdot A\_IMPO_{pr,er,cr,t} + \sum_{fa} V\_FSEFA_{se,sr,er,t} - \sum_{gv=DUT}\sum_{br} V\_FGRB_{gv,br,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t} - V\_FC_{se,er,t} - \sum_{sr} V\_FSESE_{sr,se,er,t} \qquad se{=}w \qquad [59]$$

The household income and the surplus or deficit of each agent is determined by:

$$V\_YDISP_{er,t} = \sum_{fa} V\_FSEFA_{se,fa,er,t} + \sum_{er} V\_FSESE_{sr,se,er,t} - \sum_{sr} V\_FSESE_{sr,se,er,t} \qquad \text{se=h} \qquad [60]$$

$$SURPL_{se,er,t} = V\_SAVE_{se,er,t} - V\_INV_{se,er,t} \qquad [61]$$

where:

V_SAVE$_{se,er,t}$: the savings by sector

V_INV$_{se,er,t}$: the investments in value

V_YDISP$_{er,t}$: Household's disposable income given by equation below

Prices

Intermediate and final consumers buy the composite good *A_Y* at the price *P_Y* plus taxes. Below are reported the different price formulations included in the GEM-E3-SI model:

$$P\_IO_{pr,er,t} = txit_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} + P\_Y_{pr,er,t} \qquad [62]$$

$$P\_HC_{pr,er,t} = \left(1 + txvat_{pr,er,t}\right)\left[P\_Y_{pr,er,t} + txit_{pr,er,t} \cdot \frac{WPI_t}{WPI_0}\right] \qquad [63]$$

where:

P_IO$_{pr,er,t}$: value of intermediate inputs to production

P_HC$_{pr,er,t}$: price of deliveries to private consumption by branch

$txvat_{pr,er,t}$: the rate of value added tax imposed on good *pr.*

$$P\_GC_{pr,er,t} = \left(1 + txvat_{pr,er,t}\right) \cdot \left[P\_Y_{pr,er,t} + txit_{pr,er,t} \cdot \frac{WPI_t}{WPI_0}\right] \quad [64]$$

$$P\_INVP_{pr,er,t} = \left(1 + txvat_{pr,er,t}\right) \cdot \left[P\_Y_{pr,er,t} + txit_{pr,er,t} \cdot \frac{WPI_t}{WPI_0}\right] \quad [65]$$

where:

$P\_GC_{pr,er,t}$: price of delivery to public consumption by branch

$P\_INVP_{pr,er,t}$: price of delivery to investments by branch

The unit cost of investment by sector of destination (owner) depends on its composition in investment goods (by sector of origin). This structure is represented by a set of fixed technical coefficients $tinvpv_{pr,br,er,t}$:

$$P\_INV_{br,er,t} = P\_INV0_{br,er} \cdot \sum_{pr} \frac{P\_INVP_{pr,er,t}}{p\_invp0_{pr,er}} \cdot tinvpv_{pr,br,er,t} \quad [66]$$

The producer price is given by:

$$P\_XD_{brt,er,t} = P\_PD_{brt,er,t} + txsub_{brt,er,t} \cdot \frac{WPI_t}{WPI_0} + P\_IMP_{brt,er,t} \cdot rtnc_{brt,er,t} \quad [67]$$

$$P\_PWE_{pr,er,t} = P\_PD_{pr,er,t} + txsub_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} + P\_IMP_{pr,er,t} \cdot rtnc_{pr,er,t} \quad [68]$$

where:

$P\_XD_{brt,er,t}$: the (domestic) supply price addressed to domestic demand

$P\_PWE_{pr,er,t}$: the (domestic) supply price addressed to exports

$txsub_{pr,er,t}$: the rate of subsidies

Equilibrium

The market clearance equation is:

$$A\_XD_{pr,er,t} = \begin{cases} A\_XXD_{pr,er,t} + \sum_{cr} A\_EXPO_{pr,er,cr,t} & if\ pr = brt \\ A\_Y_{pr,er,t} + \sum_{eu} A\_EXPO_{pr,er,eu,t} + A\_YVTWR_{pr,er,t} - A\_IMP_{pr,er,t} & if\ pr = brnt \end{cases} \quad [69]$$

Total supply of goods (domestically produced and imported) expended to intermediate consumption, private and public consumption and investments.

$$A\_Y_{pr,er,t} = \sum_{br} \left(A\_IO_{pr,br,er,t,} + ABIOV_{pr,br,er,t} + A\_INVPV_{pr,br,er,t}\right) + A\_HC_{pr,er,t} + A\_GC_{pr,er,t} + A\_BUILD\_ENERGYSAVE\_H_{pr,er,t} + A\_BUILD\_ENERGYSAVE\_F_{pr,er,t} \quad [70]$$

The market clearance equations for capital are:

Case 1: capital is immobile between sectors and between regions

$$A\_KAV_{pr,er,t} = A\_KAVC_{pr,er,t-1} \quad [71]$$

Case 2: mobility across sectors but not across regions

$$\sum_{pr} A\_KAV_{pr,er,t} = \sum_{pr} A\_KAVC_{pr,er,t-1} \qquad [72]$$

Case 3: Full mobility across sectors and regions

$$\sum_{pr}\sum_{er} A\_KAV_{pr,er,t} = \sum_{pr}\sum_{er} A\_KAVC_{pr,er,t-1} \qquad [73]$$

where:

$KAVC_{pr,er,t}$: the total amount of capital stock available, fixed within the time period.

Depending on the capital mobility choice, through the switch parameter *swonkm(stime)* (i.e. 0 for no mobility, 1 for mobility between sectors) , the dual price of the capital *is computed:* as *$P\_KNOKM_{pr,er,t}$* and *$P\_KNAKM_{pr,er,t}$*, respectively.

$$P\_KAV_{pr,er,t} = \begin{cases} P\_KNOKM_{pr,er,t} & if\ SWONK = 0 \\ anakm_{pr,er,t} \cdot P\_KNAKM_{pr,er,t} & if\ SWONK = 1 \end{cases} \qquad [74]$$

where:

$anakm_{pr,er,t}$ is a calibrated parameter.

Labour market

The GEM-E3-SI model allows for involuntary unemployment using a labour supply curve where wages are inversely related to unemployment. The labour supply function is calibrated to a wage elasticity of -0.1 documented in several empirical studies (see McCelland and Mok, 2012). The wage function by each occupation is:

$$P\_WRMEAN_{sk\_type,er,t} = \frac{P\_PCI}{\overline{\overline{P\_PCI}}} \cdot \left(a_{sk\_type} + \frac{b_{sk\_type}}{RT\_UNRT_{sk\_type} - edelta_{sk\_type}}\right)^{sigmawage_{sk\_type}} \qquad [75]$$

where:

$P\_WRMEAN_{sk\_type,er,t}$: the wage rate of labour by occupation

$a_{sk\_type,er,t}$: the unemployment benefit/minimum wage by occupation

$RT\_UNRT_{sk\_type,er,t}$: the unemployment rate by occupation

$edelta_{sk\_type,er,t}$: the natural rate of unemployment by occupation

$sigmawage_{sk\_type,er,t}$: calibrated parameter in the wage curve by occupation

The following equations serve to compute the unemployment rate while the equilibrium conditions in the labour market serve to compute the wage rate, which is the average nominal wage rate used to derive the labour cost by occupation $P\_LAV_{sk\_type,er,t}$.

$$RT\_UNRT_{sk\_type,er,t} = 1 - \frac{\sum_{pr} A\_LAV_{sk\_type,pr,er,t}}{A\_POPV_{sk\_type,er,t}} \qquad [76]$$

$$A\_POPV_{sk\_type,er,t} = TotLabFrc_{sk\_type,er,t} \qquad [77]$$

where:

$RT\_UNRT_{sk\_type,er,t}$: the unemployment rate by occupation

$A\_POPV_{sk\_type,er,t}$: the labour supply by occupation

$TotLabFrc_{sk\_type,er,t}$: is the total labour force by occupation measured in million hours. The unit cost of labour is computed according to the average wage rate derived from the equilibrium of the labour market.

$XLNUM_{sk\_type,er,t}$ is used in order to ensure that the computation of $tl_{sk\_type,pr,er,t}$ is consistent with the unit cost of labour of sectors both in the baseline and the scenario.

$$XLNUM_{sk\_type,er,t} = \frac{\sum_{pr} A\_LAV_{sk\_type,pr,er,t}}{\sum_{pr}\left(A\_LAV_{sk\_type,pr,er,t} \cdot tl_{sk\_type,pr,er,t}\right)} \qquad [78]$$

$$P\_LAV_{sk\_type,er,t} = \frac{tl_{sk\_type,pr,er,t} \cdot P\_WRMEAN_{sk\_type,er,t} \cdot XLNUM_{sk\_type,er,t}}{\left(1 - txfss_{sk\_type,pr,er,t}\right)} \qquad [79]$$

where:

$P\_LAV_{sk\_type,pr,er,t}$: the unit cost of labour by occupation

$tl_{sk\_type,pr,er,t}$: the relative wage rate of labour by occupation

$P\_WRMEAN_{sk\_type,er,t}$: the wage rate of labour by occupation

$txfss_{sk\_type,pr,er,t}$: the employers social security rate by occupation

$XLNUM_{sk\_type,er,t}$: the adjustment in the average wage rate based on the labour mobility and the allocation between sectors

Environment

The GEM-E3-SI environment module includes all GHGs (CO_2, CH_4, N_2O, HFC, PFC and SF_6) so as to be able to provide a consistent analysis of climate change policies. A GHG reduction policy can be implemented either through the imposition of an exogenous tax or through the introduction of an emission reduction constraint.

From a technical point of view the introduction of an exogenous carbon tax requires:

i) the activation of the appropriate switches - *swtxexobr(ghga,br,er,an)* for firms or/and swtxexoh(ghga,fn,*er*,*an*) for households (see below for switches included in GEM-E3-SI)
ii) the assignment of the desired level of carbon tax to the *txem(ghga,br,er,an)* parameter for firms and to *txemhdg(ghga,dg,er,an)* for households.

In the case where an emission reduction target needs to be introduced the following are required:

i) switch activation: *swclubbr(ghga,br,er,cc,an)* for firms or/and *swclubh(ghga,dg,er,cc,an)* for households.
ii) set of the desired target (i.e. imposing an GHG emission cap) in the *supperfeu(ghga,cc,an)* parameter.

The imposition of an exogenous carbon tax or of an emission reduction target (where a carbon price that clears the emission permit market is calculated endogenously) increases the user cost of GHG emitting activities. GHG emissions of each sector (see [80[80]) are calculated either based on energy consumption (energy related emissions) or based on production level (process related emissions). In households only CO_2 energy related emissions have been modelled (see [81]).

$$A\_EMMBR_{ghga,br,er,t} = \begin{cases} \sum\limits_{prfuel} \begin{matrix} bec_{ghga,prfuel,br,er,t} \cdot aer_{prfuel,br,er,t} \cdot \\ eaf_{prfuel,br,er,t} \cdot A\_IO_{prfuel,br,er,t} \end{matrix} & if\ ghga = poem \\ (1 - AAtot_{ghga,br,er,t}) \cdot mec_{ghga,br,er,t} \cdot A\_XD_{br,er,t} & if\ ghga = poghg \end{cases} \quad [80]$$

where:

$bec_{ghga,prfuel,br,er,t}$: emission factor for energy related GHG in the branch level

$aer_{prfuel,br,er,t}$: share of energy consumption with emissions in the branch level

$eaf_{prfuel,br,er,t}$: emission adjustment factor in the branch level

$A\_IO_{prfuel,br,er,t}$: intermediate demand of fuels in the branch level

$AAtot_{ghga,br,er,t}$: degree of abatement in the branch level

$mec_{ghga,br,er,t}$: emission factor for process related GHG

$A\_XD_{br,er,t}$: domestic production

$$A\_EMMHLND_{ghga,br,er,t} = \sum_{prfuel} bech_{ghga,prfuel,lnd,er,t} \cdot aerh_{prfuel,br,er,t} \cdot A\_HCFVPV_{prfuel,lnd,er,t} \quad [81]$$

where:

$bech_{ghga,prfuel,br,er,t}$: emission factor for energy related GHG in households

$aerh_{prfuel,br,er,t}$: share of energy consumption with emissions in households

$A\_HCFVPV_{prfuel,lnd,er,t}$: household energy demand in the consumption matrix

The respective equation for the total demand of emission permits (firms and household) is given below:

$$\begin{aligned} DEMPEREU_{ghga,cc,t} &= \sum_{er,br} \left(A\_EMMBR_{ghga,br,er,t} \cdot swclubbr_{ghga,br,er,cc,t}\right) \\ &+ \sum_{er,fn} \left(A\_EMMHLND_{ghga,fn,er,t} \cdot swclubh_{ghga,fn,er,cc,t}\right) \end{aligned} \quad [82]$$

where:

$swclubbr_{ghga,br,er,cc,t}$: switch for permit market participation for sectors

$swclubh_{ghga,fn,er,cc,t}$: switch for permit market participation for households

The market clearance of the emission permit market results in *$P\_PCLUBAG_{cc,t}$* or else in the price of emission permits. The equations below describe the market clearance.

$$\sum_{ghg} supperfeu_{ghg,cc,t} \geq \sum_{ghg} DEMPEREU_{ghg,cc,t} \qquad \text{dual variable } P\_PCLUBAG_{cc,t} \quad [83]$$

with:

$$P\_PCLUB_{ghg,cc,t} = P\_PCLUBAG_{cc,t} \quad [84]$$

where:

$supperfeu_{ghga,cc,t}$: supply of permits (user defined)

In the GEM-E3-SI the exogenous carbon tax (see [86], [88]) or the endogenous carbon price (see [85], [87]) have been assigned in the *TXENV(ghga,br,er,an)* variable for firms and in the *TXENVHDG(ghga,dg,er,an)* for households.

$$TXENV_{ghga,br,er,t} = \sum_{cc} P\_PCLUB_{ghga,cc,t} \cdot swclubbr_{ghga,br,er,cc,t} \quad [85]$$

$$TXENV_{ghga,br,er,t} = txem_{ghga,br,er,t} \cdot swtxexobr_{ghga,br,er,t} \quad [86]$$

$$TXENVHDG_{ghga,dg,er,t} = \sum_{cc} P\_PCLUB_{ghga,cc,t} \cdot swclubh_{ghga,dg,er,cc,t} \quad [87]$$

$$TXENVHDG_{ghga,dg,er,t} = txemhdg_{ghga,dg,er,t} \cdot swtxexoh_{ghga,dg,er,t} \quad [88]$$

The price signal in firms and households to abate emissions has been modelled differently in energy related (CO_2) and in process related (CO_2, CH_4, N_2O, HFC, PFC and SF_6) emissions.

In the energy related emissions, the carbon tax or the carbon price is added in the unit cost of energy which are used in firm's production [101] or in household's consumption [102].

$$P\_ENPR_{prfuel,br,er,t} = P\_IO_{prfuel,br,er,t} + \sum_{poem} \begin{matrix} TXENV_{poem,br,er,t} \cdot bec_{ghga,prfuel,br,er,t} \cdot \\ aer_{prfuel,br,er,t} \cdot eaf_{prfuel,br,er,t} \end{matrix} \quad [89]$$

$$P\_HCFV_{fn,er,t} = \sum_{pr} thcfv_{pr,fn,er,t} \cdot P\_HC_{pr,er,t} + \sum\nolimits_{poem,prfuel} \begin{matrix} TXENVDG_{poem,fn,er,t} \cdot bech_{poem,prfuel,fn,er,t} \cdot \\ aerh_{prfuel,fn,er,t} \cdot A\_HCFVPV_{prfuel,fn,er,t} \end{matrix} \Big/ A\_HCFV_{fn,er,t} \quad [90]$$

where:

P_ENPR$_{prfuel,br,er,t}$: the unit cost of energy including abatement cost in the branch level

P_IO$_{prfuel,br,er,t}$: the unit cost of energy excluding abatement cost in the branch level

P_HCFV$_{Ind,er,t}$: the unit cost of consumption by purpose including abatement cost in households

P_HC$_{pr,er,t}$: the unit cost of consumption goods excluding abatement cost in households

A_HCFVPV$_{pruel,fn,er,t}$: the household energy demand for consumption by purpose (consumption matrix)

A_HCFV$_{fn,er,t}$: the household demand for goods (consumption by purpose)

In the process related emissions, the carbon tax or the carbon price is added to the unit cost of production [91].

$$P\_PD_{br,er,t} = P\_PDBSR_{br,er,t} - PSALE_{br,er,t} + \sum_{poabx} \Big(TXENV_{poghg,br,er,t} \cdot \big(1 - AAtot_{poghg,br,er,t}\big) + AAincr_{poghg,br,er,t} \cdot \sum\nolimits_{pr} tabcost_{poghg,pr,er,t} \cdot P\_IO_{pr,er,t} \cdot CABAVV_{poghg,br,er,t} \Big) \cdot mec_{poghg,br,er,t} \quad [91]$$

where:

P_PDBSR$_{br,er,t}$: the cost of production deriving from the firm's production function,

PSALE$_{br,er,t}$: the value of free permit endowment per unit of production,

tabcost$_{poghg,pr,er,t}$: is the share of energy component (combustible) of intermediate input,

CABAVV$_{poghg.br,er,t}$: the unit cost of abatement in process related emissions.

In the GEM-E3-SI, firms and households decide the level of GHG emissions abatement endogenously. For CO_2 energy related emissions the model provides a sufficiently large number of endogenous abatement options (i.e. fuel substitution, change in power mix, adoption of advanced and energy efficient technologies etc.) whereas for each process related GHG emissions abatement options are introduced in a reduced form (exogenously estimated marginal abatement cost curves).

The optimum level of abatement for a firm of process related GHG emissions is at the point where the marginal cost of reducing one tonne of CO_2 eq. equals the carbon tax/price.

$$MCGHG_{poghg,br,er,t} \leq TXENV_{poghg,br,er,t} \qquad [92]$$

where:

$MCGHG_{poghg,br,er,t}$: the marginal abatement cost of process related greenhouse gas emissions.

The cost function which is used to determine the marginal abatement cost [93] is: $f(AA) = mac1 \cdot (e^{AA} - AA - 1)$.

$$MCGHG_{poghg,br,er,t} = \frac{WPI_t}{WPI_0} \cdot mac1_{er,poghg,br,an} \cdot (e^{AA_{poghg,br,er,an}} - 1) \qquad [93]$$

where:

$mac1_{er,poghg,br,t}$: is a marginal abatement cost coefficient for process related GHG emissions

The unit cost of abatement which take into account the abatement option possibilities is given by the equation below.

$$CABAVV_{poghg,br,er,t} = \frac{WPI_t}{WPI_0} \cdot mac1_{er,poghg,br,t} \cdot \frac{\left(e^{AA_{poghg,br,er,t}} - AA_{poghg,br,er,t} - 1\right)}{\sum_{pr} tabcost_{poghg,pr,er,t} \cdot P\_IO_{pr,er,t}} \qquad [94]$$

Demand for intermediate inputs to meet abatement purposes, *ABIOV*$_{pr,br,er,t}$ in the case of firms, is added directly to domestic demand for goods *A_Y*$_{pr,er,t}$.

$$ABIOV_{pr,br,er,t} = \sum_{poghg} \big(tabcost_{poghg,pr,er,t} \cdot CABAVV_{poghg,br,er,t} \cdot AAincr_{poghg,br,er,t} \cdot mec_{poghg,br,er,t} \cdot A\_XD_{br,er,t}\big) \qquad [95]$$

$$AAincr_{poghg,br,er,t} = AA_{poghg,br,er,t} - AAtot_{poghg,br,er,t-1} \cdot \left(1 - AAdepr_{poghg,t}\right)^{\Delta t} \qquad [96]$$

$$AAtot_{poghg,br,er,t} = AAincr_{poghg,br,er,t} + AAtot_{poghg,br,er,t-1} \cdot \left(1 - AAdepr_{poghg,t}\right)^{\Delta t} \qquad [97]$$

where:

$AAincr_{poghg,br,er,t}$: the incremental degree of abatement in the branch level

$AAdepr_{poghg,br,er,t}$: the depreciation of the abatement in the branch level

$AAtot_{poghg,br,er,t}$: the degree of abatement in the branch level

Grandfathering (free) allowances and burden sharing

In the GEM-E3-SI the simulation of grandfathering (free) allowances and burden sharing is enabled with the following “switches”: $swprimalloc_{poghg,br,er,t}$ and $swonpor_{poghg,br,er,t}$ for firms, $swprimalloch_{poghg,lnd,er,t}$ and $swonporh_{poghg,dg,er,t}$ for households and $swupr_{pr,er,t}$.

Different activation of the switches (see table of switches below for a complete list of the switches) allows for different transfers of emission permits to the firms and/or households. If agents receive additional GHG emission permits than the optimal least cost allocation then these produce an additional income that can be used to either reduce production cost or increase the firm profits (i.e. increase the firms operating surplus).

In the GEM-E3-SI model the user can select among different methods of permit allocation by setting the value of the "switch" parameter $swprimalloc_{poghg,br,er,t}$ for firms and $swprimalloch_{poghg,lnd,er,t}$ for households. The methods of permit allocation included in the GEM-E3-SI are the following:

- The supply of free allowances are equal to those demanded by each sector or/and household ($swprimalloc_{poghg,br,er,t}=0$ for firms or/and $swprimalloch_{poghg,lnd,er,t}=0$ for households), (see [98], [101])
- The supply of free allowances is based on base year emissions ($swprimalloc_{poghg,br,er,t}=1$ for firms or/and $swprimalloch_{poghg,lnd,er,t}=1$ for households), (see [99], [102])
- The supply of free allowances is based on a used defined sectoral distribution ($swprimalloc_{poghg,br,er,t}=2$ for firms or/and $swprimalloch_{poghg,lnd,er,t}=2$ for households), (see [100], [103])

$$SALEP_{ghga,br,er,t} = A\_EMMBR_{ghga,br,er,t} \cdot TXENV_{ghga,br,er,t} \quad [98]$$

$$SALEP_{ghga,br,er,t} = (1 - dporbr_{ghga,br,er,t}) \cdot emmbr\_2005_{ghga,br,er} \cdot TXENV_{ghga,br,er,t} \cdot swonpor_{ghga,br,er,t} \quad [99]$$

$$SALEP_{ghga,br,er,t} = nallo\_br_{ghga,br,er,t} \cdot TXENV_{ghga,br,er,t} \cdot swonpor_{ghga,br,er,t} \quad [100]$$

$$\begin{aligned} SALEPH_{ghga,fn,er,t} &= A\_EMMHLND_{ghga,fn,er,t} \cdot swonporh_{ghga,fn,er,t} \\ &\cdot \left(\sum_{cc} P\_PCLUB_{ghga,cc,t} \cdot swclubh_{ghga,fn,er,cc,t} + txemhdg_{ghga,fn,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot swtxexoh_{ghga,fn,er,t} \right) \end{aligned} \quad [101]$$

$$\begin{aligned} SALEPH_{ghga,fn,er,t} &= \left(1 - dporh_{ghga,fn,er,t}\right) \cdot emmhlnd\_2005_{ghga,fn,er} \cdot swonporh_{ghga,fn,er,t} \\ &\cdot \sum_{cc} P\_PCLUB_{ghga,cc,t} \cdot swclubh_{ghga,fn,er,cc,t} \end{aligned} \quad [102]$$

$$SALEPH_{ghga,fn,er,t} = nallo\_hh_{ghga,fn,er,t} \cdot swonporh_{ghga,fn,er,t} \cdot \sum_{cc} P\_PCLUB_{ghga,cc,t} \cdot swclubh_{ghga,fn,er,cc,t} \quad [103]$$

where:

$dporbr_{ghga,br,er,t}$: the reduction target at branch level for permit allocation or cap on trade

$emmbr\_2005_{ghga,br,er}$: the emissions by branch in base year (i.e. 2005)

$nallo\_br_{ghga,br,er,t}$: the user defined allocation of permits to branches

$dporh_{ghga,dg,er,t}$: the reduction target for permit allocation or cap on trade for households

$emmhlnd\_2005_{ghga,lnd,dg,er}$: the emissions of households in base year (i.e. 2005).

$nallo\_hh_{ghga,fn,er,t}$: the used defined allocation of permits to households

$SALEP_{ghga,br,er,t}$: the value of permits by branch

$SALEPH_{ghga,fn,er,t}$: the value of permits in households

The average value of permit is subtracted from the unit cost of production $P\_PDBSR_{br,er,t}$ [104] or is added to capital income [105]. When the “switch” parameter $swupr_{er,t}$ takes he value of “1” then [105] is activated otherwise the [104] is used instead.

$$PSALE_{br,er,t} = \frac{\sum_{ghga}\left(1 - SHAUCTBR_{ghga,br,er,t}\right) \cdot SALEP_{ghga,br,er,t}}{A\_XD_{br,er,t}} \tag{104}$$

$$V\_VA_{\text{"}cap\text{"},br,er,t} = P\_KAV_{br.er.t} \cdot A\_KAV_{br.er.t} + \sum_{ghga}\left(1 - SHAUCTBR_{ghga,br,er,t}\right) \cdot SALEP_{ghga,br,er,t} \tag{105}$$

where:

$SHAUCTBR_{ghga,br,er,t}$: the share of auctioned permits for branch

The additional (if positive) than the optimal GHG emission permits are given by [106] and [107] for firms and households respectively.

$$BUSAT_{ghga,br,er,t} = A\_EMMBR_{ghga,br,er,t} \cdot TXENV_{ghga,br,er,t} - SALEP_{ghga,br,er,t} \tag{106}$$

$$BUSATH_{ghga,fn,er,t} = \sum_{dg}\left(A\_EMMHLND_{ghga,fn,er,t} \cdot swonporh_{ghga,fn,er,t} \cdot TXENVHDG_{ghga,fn,er,t}\right) - SALEPH_{ghga,fn,er,t} \tag{107}$$

Energy Efficiency

The first step to incorporate the energy efficiency cost curve in the GEM-E3-SI setup is to introduce an additional factor namely the stock of energy saving technology. The cumulative energy efficiency expenditures of energy saving capital $cum\_es\_renov_{br,er,t}$, $cum\_es\_equip_{br,er,t}$, $cum\_es\_h\_renov_{er,t}$, $cum\_es\_h\_equip_{er,t}$ are created by the accumulation of the renovation and equipment goods on energy savings for firms and households respectively. The expenditure of firms and households on energy efficiency is defined exogenously by the user.

Expenditure of firms on energy efficiency technologies is transformed into demand for goods of specific sectors according to the following equation:

$$\begin{aligned} P\_IO_{pr,er,t} \cdot A\_BUILD\_ENERGYSAVE\_F_{pr,er,t} \\ = \left(\sum_{br} es\_renov\_expenditures_{br,er,t}\right) \cdot build\_energysave\_f\_renov_{pr,er,t} \\ + \left(\sum_{br} es\_equip\_expenditures_{br,er,t}\right) \cdot build\_energysave\_f\_equip_{pr,er,t} \end{aligned} \tag{108}$$

where:

$build\_energysave\_f\_renov_{pr,er,t}$: the fixed factor coefficient of materials and services required for renovation (in the model the coefficient is identical by industry)

$build\_energysave\_f\_equip_{pr,er,t}$: the fixed factor coefficient of materials and services required for advanced equipment (in the model the coefficient is identical by industry)

Expenditure of households on energy efficiency technologies is transformed into demand for goods of specific sectors according to the following equation:

$$P\_IO_{pr,er,t} \cdot A\_BUILD\_ENERGYSAVE\_H_{pr,er,t} = \left(\sum_{fn} es\_h\_expenditures_{fn,er,t} \cdot build\_energysave\_h\_coef_{pr,fn,t} \right) \quad [109]$$

where:

build_energysave_h_coef$_{pr,fn,t}$: the fixed factor coefficient of materials and services required for energy savings and differ by consumption by purpose

Equations [110],[111] provide the motion equation of the energy saving capital stock for renovation (for firms and households respectively):

$$cum\_es\_renov_{br,er,t} = cum\_es\_renov_{br,er,t-1} + \Delta t \cdot es\_renov\_expenditures_{br,er,t-1} \quad [110]$$

$$cum\_es\_h\_renov_{br,er,t} = cum\_es\_h\_renov_{br,er,t-1} + \Delta t \cdot es\_h\_expenditures_{"fn=03",er,t-1} \quad [111]$$

where:

es_renov_expenditures$_{br,er,t,}$: exogenous energy efficiency expenditures for firms renovation

es_h_expenditures$_{,fn,er,t}$: exogenous energy efficiency expenditures for households renovation

fn = 03: the consumption by purpose category expenditures for housing

Δt: the time between two GEM-E3-SI runs (usually five).

Then the energy productivity (*tge*) is formulated as a positive function of the stock of energy saving technology for firms [112] and for households [113].

$$tgen_{pr,br,er,t} = tge_{pr,br,er,t} + tge\_renov_{br,er,t} + tge\_equip_{br,er,t} + exo\_ee\_gains_{br,er,t} \quad [112]$$

$$tgqtchn_{pr,fn,er,t} = tgqtch_{pr,fn,er,t} + tgh\_house_{pr,fn,er,t} + exo\_tgqtch_{pr,fn,er,t} \quad [113]$$

$$tge\_renov_{pr,er,t} = \left(\frac{1 + cum\_es\_renov_{er,t}}{\sum_{prfele} p\_io0_{prfele,er} \cdot {a\_io0_{prfele,pr,er}}/{a\_xd0_{pr,er}} \cdot A\_XD_{pr,er,t}} \right)^{srenov_{er.t}} - 1 \quad [114]$$

$$tge\_equip_{pr,er,t} = \left(\frac{1 + cum\_es\_equip_{er,t}}{\sum_{prfele} p\_io0_{prfele,er} \cdot {a\_io0_{prfele,pr,er}}/{a\_xd0_{pr,er}} \cdot A\_XD_{pr,er,t}} \right)^{sequip_{er.t}} - 1 \quad [115]$$

$$\begin{aligned} tgh\_house_{pr,fn,er,t} &= \left(\frac{1 + cum\_es\_h\_renov_{er,t}}{\sum_{prfele} p\_hc0_{prfele,er} \cdot {a\_hcfvpv0_{prfele,fn,er}}/{a\_hcfv0_{fn,er}} \cdot A\_HCFV_{fn,er,t}} \right)^{shhrenov_{er.t}} - 1 \quad if\ renov \\ &+ \left(\frac{1 + cum\_es\_h\_equip_{er,t}}{\sum_{prfele} p\_hc0_{prfele,er} \cdot {a\_hcfvpv0_{prfele,fn,er}}/{a\_hcfv0_{fn,er}} \cdot A\_HCFV_{fn,er,t}} \right)^{shhequip_{er.t}} - 1 \quad if\ equip \end{aligned} \quad [116]$$

By using the switches sw_equip_hh, sw_renov_hh, sw_renov and sw_equip for households and firms respectively, the user can select either to compute the energy efficiency gains by utilizing the energy efficiency curve or by giving exogenously values in the parameters exo_ee_gains and exo_tgqtch.

It is assumed that there is a time lag between the expenditure and the realization of the efficiency gains. Currently this is modeled as a one period lag. The expenditure on energy efficiency, either from Households or Firms is translated to demand for certain goods and services in fixed factor proportions (the exact shares for each category are presented in Table 7).

Table 7: Sector contribution to energy efficiency investment

	Expenditure, in percent of total	
	For renovation	For equipment
Non-metallic minerals	15%	
Construction	60%	20%
Market Services	25%	20%
Advanced Electric Appliances		30%
Advanced Heating and Cooking Appliance		30%

The energy efficiency investment is financed through the savings for firms and by the households' income for households. For households a share parameter, $sh\_finance_{er,t}$ is used to allow a financing of the energy efficiency expenditure through the Government budget.

Investment now becomes:

$$V\_INV_{se,er,t} = \begin{cases} \sum_{pr}\left(tcinv_{se,pr,er,t} \cdot P\_INV_{pr,er,t} \cdot A\_INV_{pr,er,t}\right) & for\ se = "H", \\ \sum_{pr}\left(tcinv_{se,pr,er,t} \cdot P\_INV_{pr,er,t} \cdot A\_INV_{pr,er,t}\right) + \sum_{fn}\left(es\_h\_expenditures_{fn,er,t} \cdot (1 - sh\_finance_{er,t})\right) & for\ se = "G", \\ \sum_{pr}\left(tcinv_{se,pr,er,t} \cdot \left(PINV_{pr,er,t} \cdot INVV_{pr,er,t}\right)\right) + \sum_{pr} es\_renov\_expenditures_{pr,er,t} + \sum_{pr} es\_equip\_expenditures_{pr,er,t} & for\ se = "F", \\ \sum_{pr}\left(tcinv_{se,pr,er,t} \cdot PINV_{pr,er,t} \cdot INVV_{pr,er,t}\right) & for\ se = "W", \end{cases} \qquad [117]$$

where:

$tcinv_{pr,er,t}$: the share of each institutional sector in total investment.

Recycling options

The GEM-E3-SI model considers four recycling options. These options are used to ensure that the Government Budget as % of GDP remane unchanged as compared with the Baseline scenario. One or a mix of these options can be used. A positive value of recscheme[9] parameter enables the equation:

$$V\_SURPL_{"G",er,t} = surplgrffx_{er,t} \cdot V\_VU_{er,t} \qquad [118]$$

where

surplgrffx$_{er,t,}$: the government budget as % of GDP in the reference scenario

The dual variable of this equation, PB_GAP, is the difference of the Government Budget as % of GDP in the scenario with the respective value in reference. Four options are available to meet the Government Budget neutrality. Depending on the mix selected via the recscheme parameter the following equations are activated:

$$tax\_rec\_ht_{er,t} \cdot act\_t_{er,t} \cdot \frac{WPI_t}{WPI_0} = recscheme_{"HT",er,t} \cdot PB\_GAP_{er,t} \qquad [119]$$

$$\begin{aligned} &\sum_{pr} tax\_rec\_gt_{er,t} \cdot \frac{WPI_t}{WPI_0} \\ &\qquad \cdot \left[\left(\sum_{br} A\_IO_{pr,br,er,t} + ABIOV_{pr,br,er,t} + A\_INVP_{pr,br,er,t}\right) + A\_GC_{pr,er,t} + A\_HC_{pr,er,t} \right. \\ &\qquad \left. + A\_BUILD\_ENERGYSAVE\_F_{pr,er,t} + A\_BUILD\_ENERGYSAVE\_H_{pr,er,t}\right] \\ &\qquad + \sum_{pr} txvat_{pr,er,t} \cdot tax\_rec\_gt_{er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_HC_{pr,er,t} \\ &\qquad = -\, recscheme_{"GT",er,t} \cdot PB\_GAP_{er,t} \end{aligned} \qquad [120]$$

$$\sum_{pr} tax\_rec\_ps_{er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_XD_{pr,er,t} = -\, recscheme_{"PS",er,t} \cdot PB\_GAP_{er,t} \qquad [121]$$

$$\begin{aligned} &\sum_{br} \sum_{sk\_type} tax\_rec\_ss_{er,t} \cdot V\_VA_{sk\_type,br,er,t} \\ &\qquad + \sum_{br} \sum_{sk\_type} -txhss\_sk_{sk\_type,er,t} \cdot tax\_rec\_ss_{er,t} \cdot V\_VA_{sk\_type,br,er,t} + txdirtaxh_{er,t} \\ &\qquad \cdot \sum_{br} \sum_{sk\_type} txhss\_sk_{sk\_type,er,t} \cdot tax\_rec\_ss_{er,t} \cdot V\_VA_{sk\_type,br,er,t} \\ &\qquad = -\, recscheme_{"SS",er,t} \cdot PB\_GAP_{er,t} \end{aligned} \qquad [122]$$

where

tax_rec_ht$_{er,t,}$: the recycling instrument used for a lump sum transfer to household

tax_rec_gt$_{er,t,}$: the recycling instrument used for a change in the indirect tax

tax_rec_ps$_{er,t,}$: the recycling instrument used for a change in the production subsidies

tax_rec_ss$_{er,t,}$: the recycling instrument used for a change in the employers' social security contribution

act_t$_{er,t,}$: the working age population

---

[9] The equation always ensure a Government Budget as % of GDP equal to the reference case and therefore the shares in any mix of the four options should add to unity.

$recscheme_{recopt,er,t,}$: the shares to select a mix of the recycling options

$PB\_GAP_{er,t,}$: the dual variable to close the gap between the Government budget as % of GDP in scenario and reference

$txvat_{pr,er,t,}$: the vat rate by product

$txhss\_sk_{sk\_type,er,t,}$: the employees' social security contribution

$txdirtaxh_{er,t,}$: the direct tax rate in households

Power Module and the soft-link approach

The GEM-E3-SI model considers four options for the simulation of the power sector and the associated investments of power generation technologies:

- Exogenous assumptions by the user for the power mix and endogenous decision for the associated investment by power generation technology.
- Exogenous assumptions by the user for the power mix and for the associated investment by power generation technology.
- Endogenous decision via a Weibull function for the power mix and for the associated investment by power generation technology.
- Soft-link approach with a power module

The main version of the GEM-E3-SI model assume the first option that the power mix that is given exogenously and the associated investment computed endogenously by the investment function of each power generation technology. This option does not allow any substitution possibility among the power generation technologies but is rather a suitable approach to form Baseline projection. Under this option the power generation mix is defined by the user by giving values in the $dio_{prtec,or\_ele,er,t}$.

An endogenous power mix is possible by enabling the equation [123] while using the switch swxdiotec (i.e., swxdiotec = 1)

$$XDIO_{prtec,er,t} = \frac{dio_{prtec,pr\_ele,er,t} \cdot \left(\frac{p\_io0_{prtec,er}}{P\_IO_{prtec,er,t}}\right)^{stec_{er,t}}}{\sum_{prtec}\left[dio_{prtec,pr\_ele,er,t} \cdot \left(\frac{p\_io0_{prtec,er}}{P\_IO_{prtec,er,t}}\right)^{stec_{er,t}}\right]} \qquad [123]$$

where

$stec_{er,t}$: the elasticity of substitution parameter in the power generation technologies

Although this option, the single-nest approach, allows for substitution between the power generation technologies may provide unrealistic results. Under this option, it is assumed that each technology is substituted by all the others by using the same analogy. A change in price of one technologies implies a uniform impact in the rate of technical substitution among the pair of this technology with the others.

To overcome this issue, a simple power generation model has been developed for modelling the power sector and a soft-link approach can be followed. The soft-link approach extends the exogenous power mix approach by introducing substitution possibilities of the power sector and allows a better representation of the associate investment requirements of each power generation technology. The investment decision is based on technoeconomic assumptions and the optimal choice minimize the overall system cost.

The simple power model has the following characteristics:

- Non-linear problem
- 4 technologies (Fossil, RES, Nuclear, Hydro)
- Time period: 2020 – 2050 (annual)
- Full foresight forward looking expectations of investment

The objective function of the power sector [124] is to minimize the energy system cost. The energy system cost is represented in the model by the cost of providing the supply for the electricity demanded and by paying the capital and operation cost of any un-used capital stock.

$$OBJ = \sum_{t}\sum_{tech} PTECH_{tech,t} \cdot QTECH_{tech,t} + \sum_{t}\sum_{tech} UN\_VCost_{tech,t} \cdot UN\_Capacity_{tech,t} \cdot cf_{tech,t} \qquad [124]$$

where

$PTECH_{tech,t}$: the levelized cost of electricity by power generation technology

$QTECH_{tech,t}$: the electricity produced by power generation technology

$UN\_VCost_{tech,t}$: the cost of the un-used power generation technologies

$UN\_Capacity_{tech,t}$: the capacity of the un-used power generation technologies

$cf_{tech,t}$: the capacity factor of each power generation technology (transforming MW to MWh)

The total electricity produced should be greater than the demand for each year [125].

$$\sum_{tech} QTECH_{tech,t} = QDemand_{t} \qquad [125]$$

where

$QDemand_{t}$: the exogenous demand provided by the user or by the GEM-E3-SI model

The maximum production of electricity by each power generation technology is limited by a capacity factor [126].

$$Cap\_Stock_{tech,t} = \frac{QTECH_{tech,t}}{cf_{tech,t}} \qquad [126]$$

where

$Cap\_Stock_{tech,t}$: the capacity of each power generation technology

The capacity of each power generation technology increases by the endogenous investment decision of the model and depreciates with a constant factor via a stock motion equation [127].

$$Cap\_Stock_{tech,t} = Cap\_Stock_{tech,t-1} \cdot \left(1 - depr_{tech,t-1}\right) + INV_{tech,t} \qquad [127]$$

where

$INV_{tech,t}$: the new additions in the capacity of each power generation technology

$depr_{tech,t}$: the depreciation rate of the existing capacity of each power generation technology

The unit cost of capital is determined by the exogenous investment cost of each power generation in each year and the capital cost of the existing capacity after the depreciation [128].

$$PCAP_{tech,t} = \frac{PCAP_{tech,t-1} \cdot Cap\_Stock_{tech,t-1} \cdot \left(1 - \ depr_{tech,t-1}\right)}{Cap\_Stock_{tech,t}} + \frac{pcapnew_{tech,t} \cdot INV_{tech,t}}{Cap\_Stock_{tech,t}} \qquad [128]$$

where

$pcapnew_{tech,t}$: the capital cost of new additions in the capacity of each power generation technology

The unused capacity of each power generation technology is determined by:

$$UN\_Capacity_{tech,t} = Cap\_Stock_{tech,t} - \frac{QTECH_{tech,t}}{cf_{tech,t}} \qquad [129]$$

and the cost of the unused capacity that is added in the energy system cost in the objective function is:

$$UN\_VCost_{tech,t} = PCAP_{tech,t} + a_{tech,t} + b_{tech,t} \cdot \frac{UN\_Capacity_{tech,t}}{cf_{tech,t}} \qquad [130]$$

where

$a_{tech,t}$: a calibrated parameter. A fixed cost to represented the flexibility of the power generation to switch on/off

$b_{tech,t}$: a calibrated parameter. A linear cost as a function to unused capacity to limit the level or replacement of existing technologies with investment in new technologies.

The levelized cost of electricity is determined by the unit cost of each of input factor:

$$PTECH_{tech,t} = PCAP_{tech,t} + plav_{tech,t} + pmat_{tech,t} + pene_{tech,t} + ctax_{tech,t} \qquad [131]$$

where

$plav_{tech,t}$: the unit cost of labour

$pmat_{tech,t}$: the unit cost of materials

$pene_{tech,t}$: the unit cost of fossil fuels

$ctax_{tech,t}$: the exogenous carbon tax

Switches

Several GEM-E3-SI modules come with alternative features and assumptions. The choice of which of the latter will be included in the model is left to the modeler and depends on the policies under study. Indicative are the environmental module (alternative options include the introduction of exogenous carbon tax, introduction of emission reduction targets, etc.) and the budget balancing mechanisms available in GEM-E3-SI (these include endogenous determination of interest rates, setting of constant budget deficit/surplus as share of GDP, etc.). The GEM-E3-SI model is fitted with switch parameters which enable the activation of specific equations in the model linked to the different modules and modelling assumptions. Equations are activated if the switch parameter linked to each equation takes the respective value (i.e., 1). In contrast the equations are deactivated and do not enter the model if the switches linked to the latter take the value of zero (0). Table 8 summarizes the switches found in the GEM-E3-SI model and the associated model option.

Table 8: Switch parameters and related features in GEM-E3-SI model

“switch” parameter	Description
Environmental Switches	

SWTXEXOBR(ghga,br,er,t)	Introduction of exogenous carbon tax (txem) on firms, for selective pollutants (ghga), in activities (br), countries (er) and time (t).
SWTXEXOH(ghga,fn,er,t)	Introduction of exogenous carbon tax (TXEMHDG) on households, for selective pollutants (ghga), in consumption categories (fn), countries (er) and time (t).
SWCLUBBR(ghga,br,er,cct,t)	Introduction of an emission reduction target on a branch level (br) for the region (er) which belong on the club (cct) for selective pollutants (ghga), in activities (br), countries (er) and time (t).
SWCLUBH(ghga,fn,er,cct,t)	Introduction of an emission reduction target on households for the region (er) which belong on the club (cct), for selective pollutants (ghga), in consumption categories (fn), countries (er) and time (t).
SWONPOR(ghga,pr,er,t)	Introduction of allocation of emission permits with grandfathering (free allowances) on firms for selective pollutants (ghga), in activities (br), countries (er) and time (t).
SWONPORH(ghga,fn,er,t)	Introduction of allocation of emission permits with grandfathering (free allowances) on households for selective pollutants (ghga), in consumption categories (fn), countries (er) and time (t).
SWPRIMALLOC(ghga,br,er,t)	Introduction of the method to be used to allocate the emissions permits with grandfathering (free allowances) on firms for selective pollutants (ghga), in activities (br), countries (er) and time (t).
SWPRIMALLOCH(ghga,fn,er,t)	Introduction of the method to be used to allocate the emissions permits with grandfathering (free allowances) on households for selective pollutants (ghga), in consumption categories (fn), countries (er) and time (t).
SWUPR(pr,er,t)	Enables the use of revenues from free emission permits. If zero then revenues from free permits reduce the unit cost of production of each branch (pr), country (er) and time (t) else if one increase the firms' capital income.
	Budget balancing Instruments
SWONCA(er,t)	Interest rate endogenously estimated so as the current account deficit/surplus as a percentage of GDP, expressed in current prices, remains unchanged in all scenarios. In that way, the country is not allowed to increase its borrowing in order to comply with the environmental policy.
SWONCAEU(er,t)	Interest rate endogenously estimated so as the current account deficit/surplus as a percentage of GDP, expressed in current prices, for the EU27 zone remains unchanged in all scenarios.
recscheme(recopt,er,t)	Activation of a constraint to keep the government's deficit/surplus as a percentage of GDP unchanged in all scenarios. This option can be used for recycling to the economy the extra government revenues e.g. from permit sales in case of auctioning. The user selects the share of participation of each recycling option in order to meet the Government Budget target. A mix of four different options can be selected: • the dual variable (TAX_REC_HT) is used as a lumb sum transfer which increase the household income.

	- the dual variable (TAX_REC_SS) is used as a rate which reduce social security contributions. - the dual variable (TAX_REC_IT) is used as a tax which reduce the general taxation. - the dual variable (TAX_REC_PS) is used as a subsidy which reduce the unit cost of production.
SWGC(er,t)	Activation of endogenous/exogenous calculation of government consumption. If “0” the government consumption is equal to the exogenous parameter gctv(er,stime). If “1” the government consumption is a constant share of GDP.
Other switches	
SWOKM(er,t)	Introduction of capital mobility choice in capital market. If “0” there is no capital mobility. If “1” there is a full capital within country across sectors.
SWXDIOTEC	Activation of endogenous/exogenous calculation of power mix share. If “0” power mix shares are set exogenously by the user. If “1” power mix shares are calculated endogenously through a Weibull function.

3 User manual

This section is the user manual of the GEM-E3-SI model and provides a detailed description of the main steps required in order to produce a Baseline scenario and implement policy scenarios. In particular, a description of (i) the parameterization required to form the evolution of the Slovenian economy until 2050 under a Baseline context, (ii) the scenario template provided in GAMS files and in spreadsheet files that allows the user to simulate various policy scenarios regarding an exogenous carbon tax, an endogenous GHG emission target, renewable policies and energy efficiency policies and (iii) the soft-link approach with a power generation module that has been developed to extend the substitution possibilities of the power sector in both the Baseline and in the scenario runs.

A number of diagnostics and policy scenarios have been developed in section 5 by following a step-by-step approach to complement the user manual with illustrative examples.

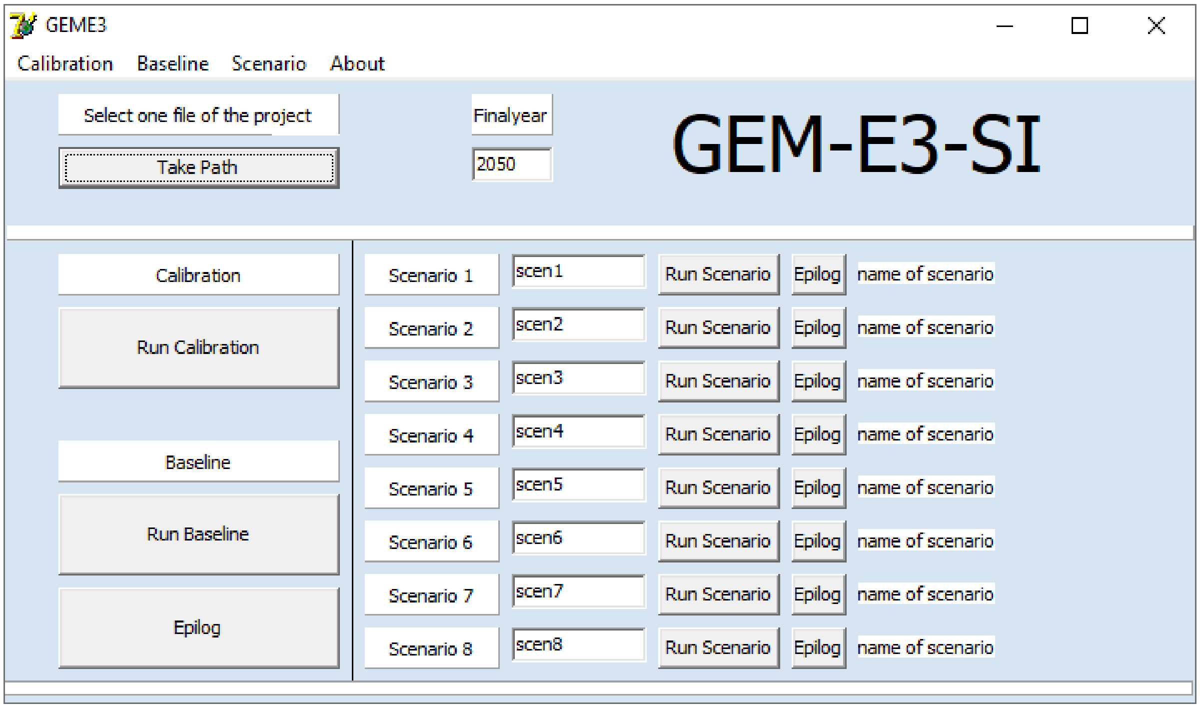
This section is structured as follows: the next subsection presents the user interface. Section 0 focuses on the main steps required for producing a Baseline. Section 0 describes the scenario template and section 0 analyze the power sector and the main steps required for the soft-link approach with the simple power generation model.

User interface, folders and file structure

GEM-E3-SI graphical user interface

The use of GAMSIDE or other editors is necessary to modify the model, but it is not required in order to run the calibration or the model. These operations are controlled by the Graphical User Interface (GUI) of the GEM-E3-SI model (Figure 8).

Figure 8: Graphical user interface of the GEM-E3-SI model

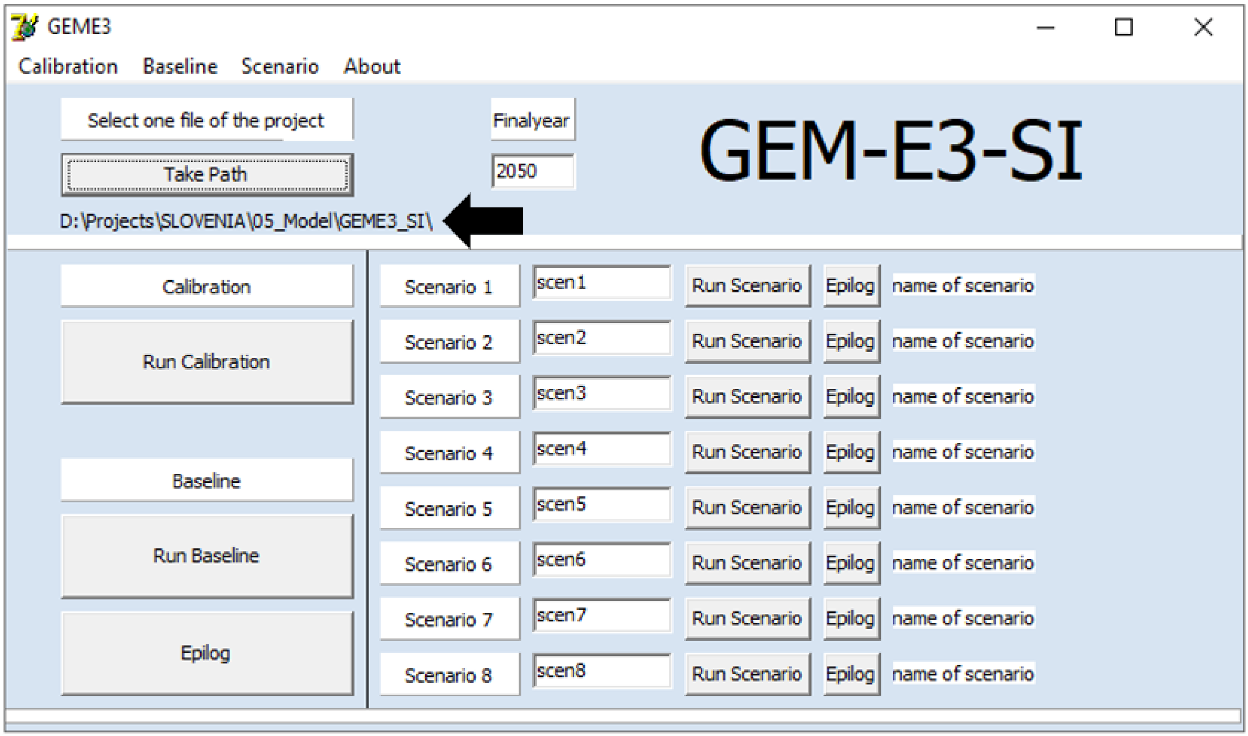


Finalyear 2050

scen1
scen2
scen3
scen4
scen5
scen6
scen7
scen8

The GUI initiates with double-clicking of the *Run_GEM_E3_SI.exe*. The first action is to load the path where the model (GEM-E3-SI folder) is copied in the machine of the user. This is performed by pressing the *Take Path* button and selecting the *Run_GEM_E3_SI.exe* located in the relevant folder. Then the GUI displays the path of the model. In Figure 9 an example of path setting for the GEM-E3-SI model in the GUI is indicated with a black arrow. The user should double check that the path selected corresponds to the right working folder directory.

Figure 9: GUI of the GEM-E3-SI model – Path declaration



Finalyear 2050

D:\Projects\SLOVENIA\05_Model\GEME3_SI\

Scenario 1 scen1

Scenario 2 scen2

Scenario 3 scen3

Scenario 4 scen4

Scenario 5 scen5

Scenario 6 scen6

Scenario 7 scen7

Scenario 8 scen8

The GUI of the GEM-E3-SI model allows the user to run:

1. the calibration of the GEM-E3-SI
2. the Baseline scenario
3. Policy Scenarios

3.1.1.1 Run Calibration

Model calibration is initiated by pressing the *Run Calibration* button. This button creates and run the batch file[10] *Calibration.bat* in the folder directory: *…\GEMCAL\runfiles* and run GAMS by using an external source (i.e., via MS-DOS). Once the calibration phase is over, the following files are generated:

- *Calibration.gdx* (stored at *…\GEMCAL\RUN_GDX*) that includes all elements of the model. This file is used for routine checks by the user.

---

[10] The batch file is a text file that contains a series of commands that can be run by a program. In the GEM-E3-SI model the batch files are used to perform the following actions: (1) Create the necessary .gdx files where all the parameters, variables and sets are stored, (2) Load the sets that contain the running period of the model and (3) Execute GAMS to run the calibration, reference and scenario of the GEM-E3-SI model

- *_GEMA.g00* (stored at *…\GAMSSAVE*). This file is the basis from which the model loads all parameters and initial levels for variables in order to run.
- *C00_start.lst* (stored at *…\GEMCAL\runfiles)*. The list file gives information to the user regarding the process of compilation and execution of the model code.

A number of model checks has been developed to ensure that the starting point of the model is based on balanced data, with demand equal supply to the capital, labour and product markets. The GAMS code can be found in the: *C06_Check_Model.gms* (stored at *…\GEMCAL\)*. If any error found through these checks, the execution will be aborted and an error message will inform the user.

3.1.1.2 Run Baseline

The first step to run the model is to define the relevant time period in the box *Finalyear* (the end year of the simulation is inserted; the default value is 2050). Once the time period has been defined, the *Run Baseline* button needs to be pressed so that the baseline scenario is initiated. This button creates and run the batch file *Baseline.bat* in the folder directory: *…\GEMMOD\runfiles*. Following the completion of the baseline scenario three files are created:

- *_Baseline.gdx* file that contains all the elements of the model. The file is located in the *RUN_GDX* folder, inside the *GEMMOD* folder.
- *_GEMRL.g00* file that is used in the epilogue reporting section. The epilogue section makes all the necessary computations that are required for the reporting of the model variables. The file is located in the *GAMSSAVE* folder.
- *M00_start.lst* (stored at *…\GEMMOD\runfiles)*. The list file gives information to the user regarding the process of compilation and execution of the model code.

There is a pause in the execution of the commands after the generation of the files above. By pressing any key the next commands in the batch file runs the epilogue of the model. The epilogue of the model is used for reporting and uploading the results in csv files. The following files are created by the epilogue of the model:

- *Baseline.gdx* file that contains all the elements of the model and the epilogue of the model. The file is located in the *RUN_GDX* folder, inside the *GEMMOD* folder.
- %region%_det_ref.csv files that each file (one csv by region) contains the model results that are selected for reporting. These files are uploaded on the folder: *…\GEMSCEN\REFERENCE\RESULTS*.
- *epiref.lst* (stored at *…\GEMMOD\runfiles)*. The list file gives information to the user regarding the process of compilation and execution of the model epilogue.

The button Epilog that is found below the Run Baseline button is an option to the user to run only the epilogue of the model. Once the Baseline simulation is complete the user might require to perform an additional computation in the epilogue of the model or a change in the report. The button Epilog allows the user running only the second part of the Run Baseline button. That is, running only the epilogue of the model without running again the Baseline.

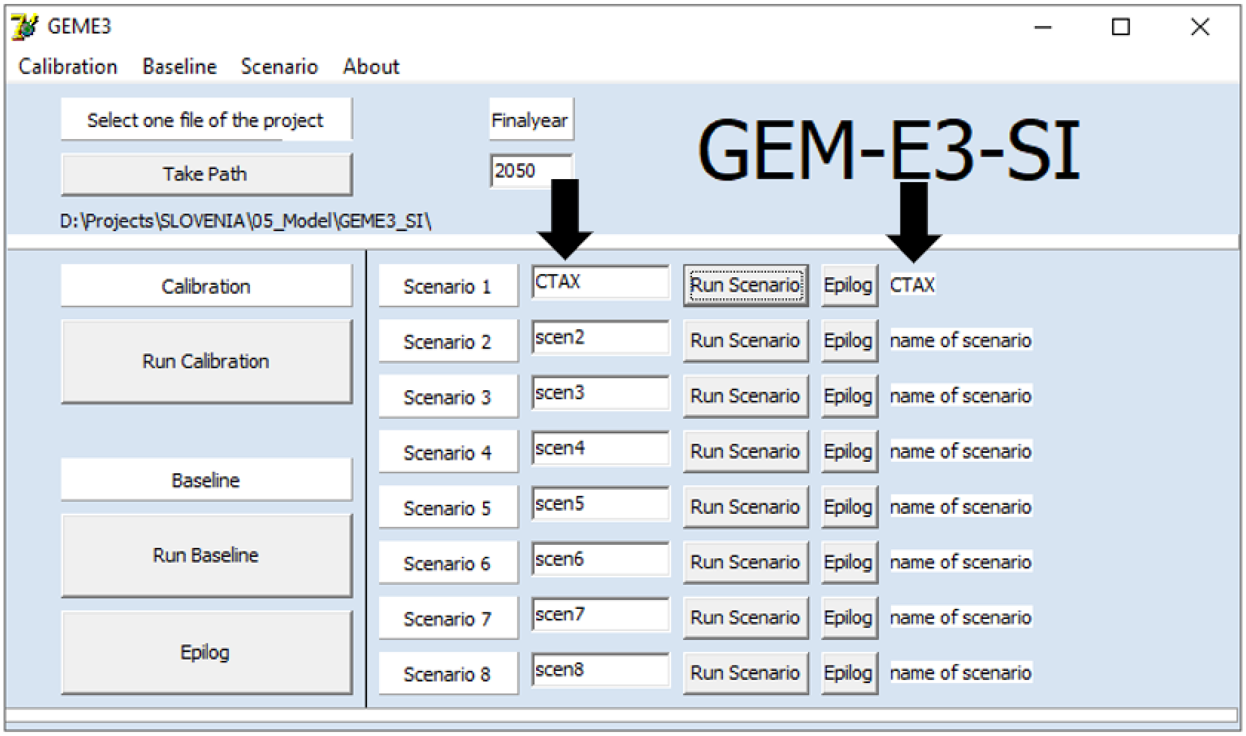
A number of model checks have been developed to ensure that in the Baseline, the input output tables, the consumption and investment matrices are balanced, demand equals supply to the capital, labour and product markets etc.. The GAMS code for these checks can be found in the: *EPILOG_CHECKS.gms* (stored at *…\GEMMOD\REPORT\)*. If any error exists, the execution will be aborted and the respective error message will inform the user.

3.1.1.3 Run Scenario

In order to run a scenario the user initially need to decide the scenario name. The folder *00_Scenario_name* (stored at the *…\GEMSCEN\SCENARIO*) contains the main files required for setting a scenario. The user can copy – paste the *00_Scenario_name* folder and rename it together with all the files included within this folder. The scenario name decided by the user (for instance: *CTAX*) should be exactly the same in all the files.

Following this, the name of the scenario is written in the text box next to Scenario 1 in the GUI. Figure 10 provides an example of scenario declaration, where the scenario *CTAX* is set in the *Scenario* box (indicated with the black arrow). Then *Run Scenario* is pressed for scenario simulation. Once the *Run Scenario button* is pressed the scenario name will appear next to the *Epilog* button.

Figure 10: GUI of the GEM-E3-SI model – Scenario setting



Finalyear 2050

D:\Projects\SLOVENIA\05_Model\GEME3_SI\

Scenario 1 CTAX CTAX
Scenario 2 scen2 name of scenario
Scenario 3 scen3 name of scenario
Scenario 4 scen4 name of scenario
Scenario 5 scen5 name of scenario
Scenario 6 scen6 name of scenario
Scenario 7 scen7 name of scenario
Scenario 8 scen8 name of scenario

The Run Scenario button creates and run the batch file *%NameScenario%_Scenario.bat* in the folder directory: *…\GEMMOD\runfiles*. Following the completion of the scenario three files are created:

- *_%NameScenario%_Scenario.gdx* file that contains all the elements of the model. The file is located in the *RUN_GDX* folder, inside the *GEMMOD* folder.

- *_GEMSL_%NameScenario%.g00* file that is used in the epilogue reporting section. The epilogue section makes all the necessary computations that are required for the reporting of the model variables. The file is located in the *GAMSSAVE* folder.
- *S00_start.lst* (stored at *…\GEMMOD\runfiles)*. This list file gives information to the user regarding the process of compilation and execution of the model code.

There is a pause in the execution of the commands after the generation of the files above. By pressing any key the next commands in the batch file runs the epilogue of the model. The epilogue of the model is used for reporting and uploading the results in csv files. The following files are created by the epilogue of the model:

- *%NameScenario%_Scenario gdx* file that contains all the elements of the model and the epilogue of the model. The file is located in the *RUN_GDX* folder, inside the *GEMMOD* folder.
- %region%_det_scen.csv files that contains the model results (one csv by region) that are selected for reporting. These files are uploaded on the folder: *…\GEMSCEN\SCENARIO\%NameScenario% \RESULTS*.
- *episcen.lst* (stored at *…\GEMMOD\runfiles)*. This list file gives information to the user regarding the process of compilation and execution of the model epilogue.

The button Epilog that is found next to the Run Scenario button is an option to the user to run only the epilogue of the model. Once the scenario run has finished the user might require to perform an additional computation in the epilogue of the model or a change in the report. The button Epilog allows the user running only the second part of the Run Scenario button. That is, running only the epilogue of the model without running again the scenario.

A number of model checks has been developed to ensure that in the scenario run the input output tables, the consumption and the investment matrices are balanced, demand equals supply to the capital, labour and product markets etc.. The GAMS code can be found in the: *EPILOG_CHECKS.gms* (stored at *…\GEMMOD\REPORT\)*. If any error arise, the execution will be aborted and an error message will inform the user.

Reporting

Once the GEM-E3-SI reference or scenario is simulated a given set of results is exported in *csv* form by the epilogue of the model. These *csv* files are collected by a macro enabled excel file that prepares the formatted presentation of the results.

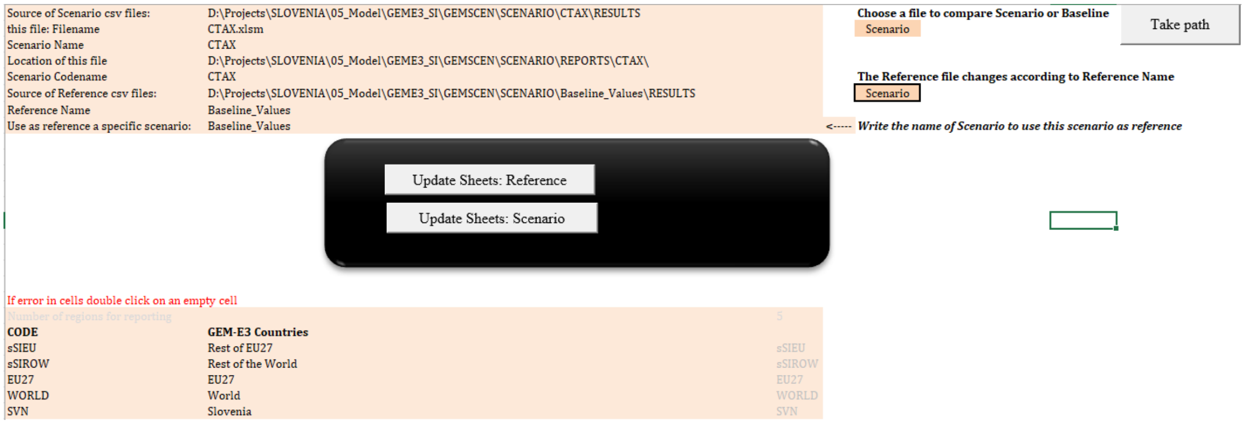
For the Baseline the name of the excel file is *report_det_baseline.xlsm* and the file is stored at the folder: …*GEMSCEN\SCENARIO\REPORTS\Baseline*. For the scenarios, the name of the excel file should follow the name decided by the user: *report_det_%NameScenario%.xlsm*. It is recommended to the user to copy-paste the scenario: *report_det_Baseline_Values.xlsm* and rename it accordingly.

In the sheet *Update_Sheets* of the report file (i.e., *report_det_baseline.xlsm*), the user can select the scenarios to update. To do so the user needs to identify the locations of the scenarios' files in the machine. In cells B1 and B6 the user can manually enter the location of the *csv* files which are used for the update of the report (see Figure 11 for an example). The sheet contains formulas in the cells K2 and K4 and by pressing the command button ***Take path*** the paths of the excel file will be automatically updated.

Once the correct path of the reference and scenario *csv* files is given in cells *B1* and *B6* the buttons *Update Sheets Reference* and *Update Sheets Scenario* should be pressed in sequence in order to perform the update. Once the button is pressed the update of the excel file initiates. The file is linked with the *.csv* files from which the new figures are imported to the report. The update is done with automated tasks via macros. If macros are not enabled a security warning appears not allowing the user to run the macro and update the sheets.

The user can give the name of any scenario to be used as a reference for comparison purposes. To do so, the user should write in the cell B9 the name of the scenario. In Figure 11 the scenario CTAX is compared with the scenario Baseline_Values.

Figure 11: Reporting the results of GEM-E3-SI model in excel file



Source of Scenario csv files:	D:\Projects\SLOVENIA\05_Model\GEME3_SI\GEMSCEN\SCENARIO\CTAX\RESULTS
this file: Filename	CTAX.xlsm
Scenario Name	CTAX
Location of this file	D:\Projects\SLOVENIA\05_Model\GEME3_SI\GEMSCEN\SCENARIO\REPORTS\CTAX\
Scenario Codename	CTAX
Source of Reference csv files:	D:\Projects\SLOVENIA\05_Model\GEME3_SI\GEMSCEN\SCENARIO\Baseline_Values\RESULTS
Reference Name	Baseline_Values
Use as reference a specific scenario:	Baseline_Values

Choose a file to compare Scenario or Baseline
Scenario

The Reference file changes according to Reference Name
Scenario

<----- ***Write the name of Scenario to use this scenario as reference***

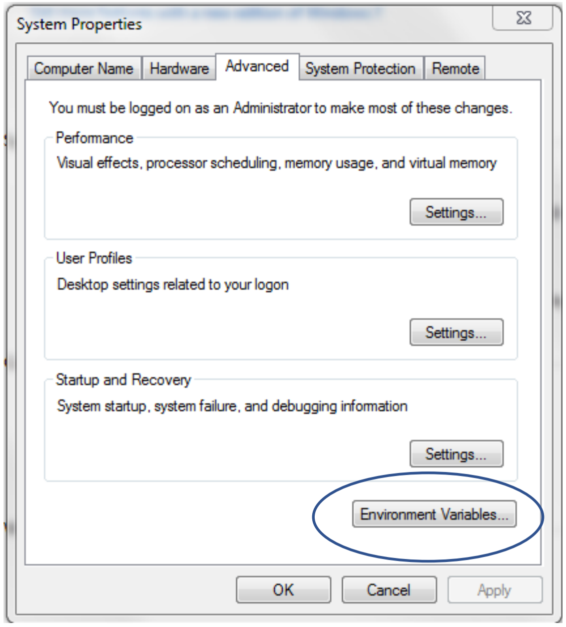
If error in cells double click on an empty cell

Number of regions for reporting		5
CODE	**GEM-E3 Countries**	
sSIEU	Rest of EU27	sSIEU
sSIROW	Rest of the World	sSIROW
EU27	EU27	EU27
WORLD	World	WORLD
SVN	Slovenia	SVN

GAMS file path

The execution of GAMS either from the command prompt or using the GEM-E3-SI GUI requires that the path of the GAMS executable file is included in the Windows path file. This is normally performed during the GAMS installation procedure. In the case where *GAMS.exe* is not in the path the message error *"GAMS is invalid command" appears*. In order to amend this error, the user needs to go to the system properties and select *Environment Variables* (Figure 12).

Figure 12: Windows 7 System properties



You must be logged on as an Administrator to make most of these changes.

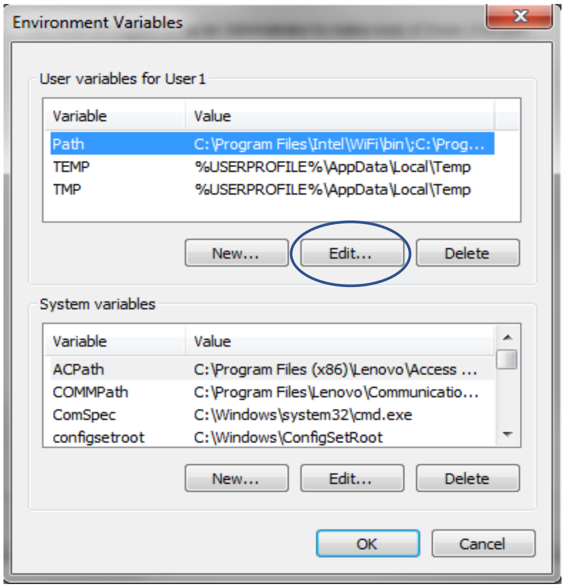
Performance: Visual effects, processor scheduling, memory usage, and virtual memory

User Profiles: Desktop settings related to your logon

Startup and Recovery: System startup, system failure, and debugging information

Then in the *Environment Variables* window the user should select the variable path (*Path)* and press *Edit*. This is were the exact location of the *gams.exe* file in the PC must be indicated (i.e. *c:\software\GAMS.exe*). Caution needs to be taken at this stage so as not to delete the path of other environmental variables.

Figure 13: Windows 7 Environment variables



User variables for User1

Variable	Value
Path	C:\Program Files\Intel\WiFi\bin\;C:\Prog...
TEMP	%USERPROFILE%\AppData\Local\Temp
TMP	%USERPROFILE%\AppData\Local\Temp

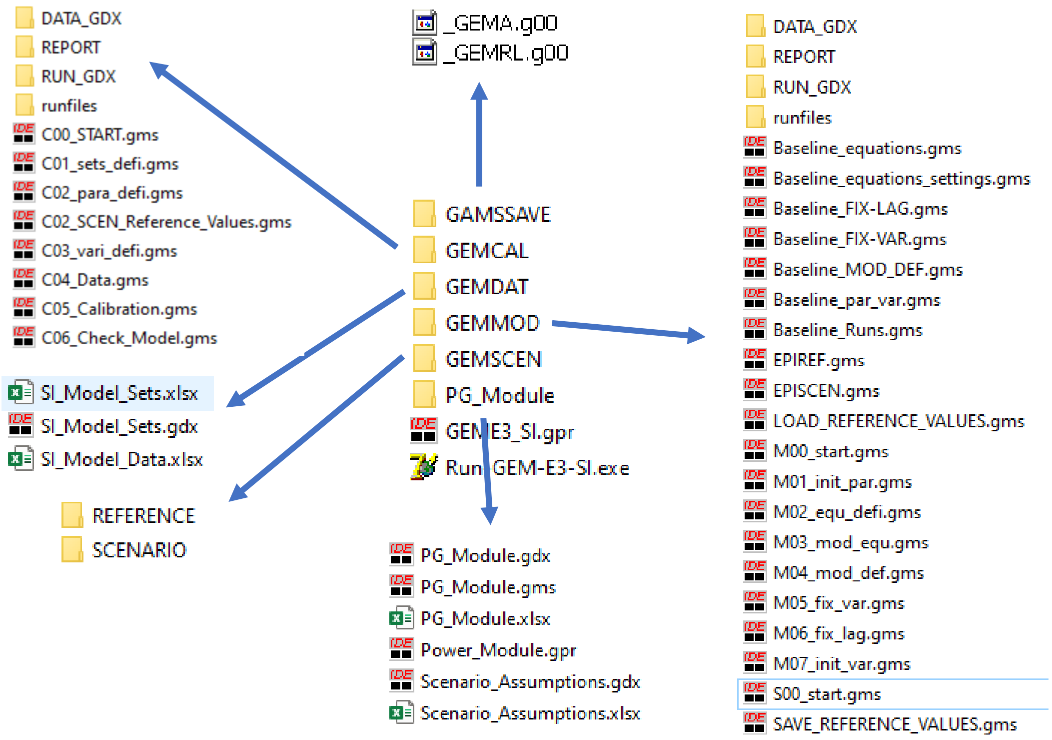
System variables

Variable	Value
ACPath	C:\Program Files (x86)\Lenovo\Access ...
COMMPath	C:\Program Files\Lenovo\Communicatio...
ComSpec	C:\Windows\system32\cmd.exe
configsetroot	C:\Windows\ConfigSetRoot

Files and folder structure

The GEM-E3-SI model is organized in several files and folders. Figure 14 depicts the file and folder structure of the model. Model encrypted in GAMS code is stored in *G00* files located in the *GAMSSAVE* folder. All calibration files are stored in the *GEMCAL* folder, data files are stored in the *GEMDAT* folder, the model files are stored in the *GEMMOD* folder and the scenario files are located in the *GEMSCEN* folder.

Figure 14: Folder and file structure of the GEM-E3-SI model



The file that starts the calibration of the GEM-E3-SI model is the *C00_START.gms* located in the *GEMCAL* folder. In the same folder the model sets, parameters and the variables for calibration are defined in the *C01_sets_defi.gms, C02_para_defi.gms* and *C03_vari_defi.gms* files respectively. File *C04_Data.gms* loads the data required for the calibration of the model from the excel file *SI_Model_Data.xlsx. C05_Calibration.gms* runs the calibration while *C06_Check_Model.gms* performs model calibration checks.

Model data files are located in the *GEMDAT* folder. This folder includes all the data used in the model. The *SI_Model_Data.xlsx* file includes the SAMs and other model data while the *SI_Model_SETS*.xlsx file includes the sets used in the GEM-E3-SI model (countries, sectors, emissions etc.)

The file that runs the Baseline of the GEM-E3-SI model is the M00_start.*gms* file located in the *GEMMOD* folder. The *DATA_GDX* folder is where the model data *gdx* files are saved and it is also located in the *GEMMOD* folder. The *REPORT* folder contains the *.gms* files that produce the model reports. *RUN_GDX* folder contains the *.gdx* files of the model. *Runfiles* folder contains the temporary run files of the model. *EPIREF.gms and EPISCEN.gms* are used for model reference and scenario reporting. *M01_init_par.gms* file initializes model parameters. *M02_equ_defi*.gms, M03_*mod_equ.gms* and *M04_mod_def.gms* files define and set the model equations. *M05_fix_var.gms* sets the variables that are assumed fixed in the model while *M06_fix_lag.gms* sets the fixed lags of lagged variables of the model. *M07_init_var.gms* file initializes the model's variables. The file that runs the model scenario is the *S00_start.gms* file.

The PG_Module folder contains a simple satellite power model that have been developed to increase the substitution possibilities of the power sector by using specific technoeconomic assumptions by power generation technology. This module is soft-linked with the GEM-E3-SI model (see section below). The excel PG_Module.xlsx contains the technoeconomic assumptions of the power generation technologies used in the model, the model code is defined in the PG_Module.gms and the excel file Scenario_Assumptions.xlsx is used to apply additional to the reference scenario assumptions in the case of a standalone run of the power model.

The Baseline Scenario

Preparatory stages

The projection of a country's economic system is a complex task that requires the consideration of the multiple interactions between the various components of an economic system in a transparent and consistent manner. The Baseline scenario is a projection of the (Slovenian) economy up until 2050. Its objective is to reflect the future structure of the Slovenian economy in an informed and consistent manner. That is to introduce changes to the economic system that are consistent with recent trends and policies adopted and are consistent with economic growth theories[11].

The construction of the baseline involves the following stages (schematically also presented in Figure 15):

- ✓ Collection of short & long-term projections on key socio-economic aggregates (e.g. GDP, population)
- ✓ Identification of recent trends affecting the economic development
- ✓ Collection of already adopted policies
- ✓ Development of the growth narrative[12]
- ✓ Elaboration of macroeconomic aggregates to components
- ✓ Use of the GEM-E3-SI model baseline tool to map and reconciliate all exogenous projections into a consistent quantified projection

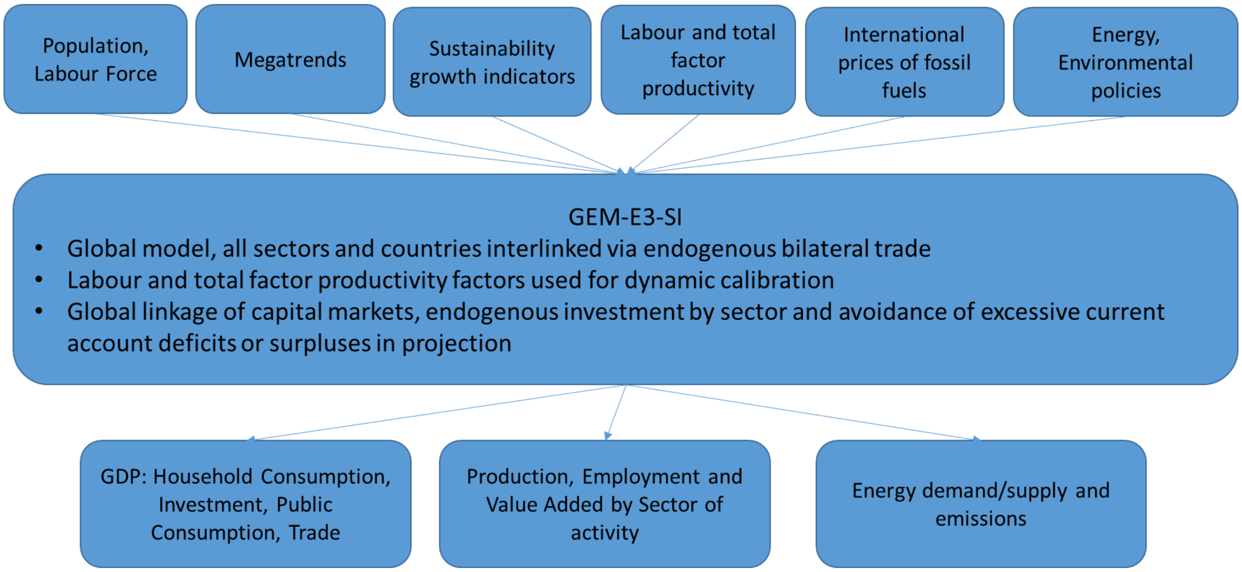
The model instruments to quantify the baseline scenario include population, labour force, energy efficiency improvements, labour productivity, technical progress, consumption patterns, production structure, public consumption and fiscal rates, firms expectations regarding how future economic outcomes may influence current decisions (e.g., investment); *and* policies that are adopted or already in force at the time of developing the Baseline scenario, i.e., environment, energy, tax policies.

---

[11] Growth should be attributed to specific factors (e.g. labour productivity, technical progress, capital accumulation, demand boost etc.) and need to address long term sustainability conditions such as the reduction of excessive deficits/surpluses.

[12] The structure of the economy, i.e., whether growth is service- or industry-oriented and the GDP components, i.e., whether GDP is driven by consumption (consumer goods), or investments (capital goods). The growth narrative is essential as an industry-oriented growth is expected to have higher energy intensity compared to a services-oriented growth and hence it is asymmetrically impacted by climate policies.

Figure 15: Schematic representation of Baseline scenario building



Baseline with exogenous instruments

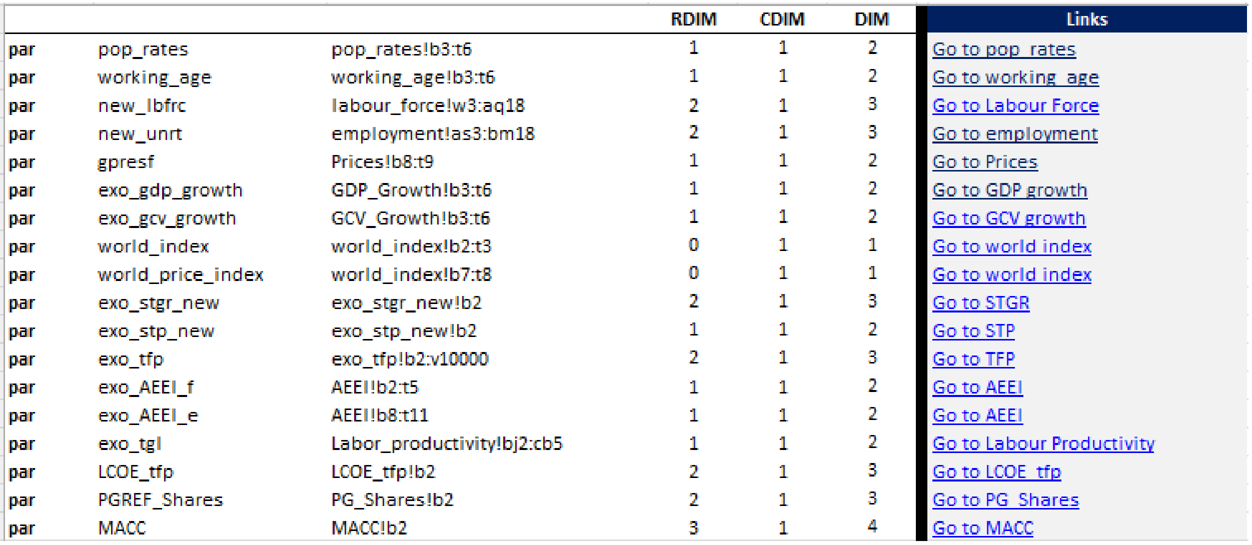
The M00_start.gms file initiates the Baseline. The switch *equ_base* is used in this file to allow the user to choose to run the Baseline either with exogenous instruments or with endogenous specified targets.

By setting *equ_base = “0”*, the model runs with exogenous instruments. The exogenously defined assumptions in the key parameters of the model for the Baseline are defined by the user in the excel file: Baseline_Assumptions.xlsx (Figure 16) which is located in the …\GEMSCEN\REFERENCE folder directory.

The user can define exogenously the:

- Annual growth rates of population (*sheet:* pop_rates, *data area:* b3:t6)
- Annual growth rates of working age population (*sheet:* working_age, *data area:* b3:t6)
- Labour force in million hours by occupation (*sheet:* labour_force, *data area:* w3:aq18)
- Unemployment rates by occupation (*sheet:* employment, *data area:* as3:bm18)
- Annual growth rate of the international crude oil price (*sheet:* Prices, *data area:* b8:t9)
- Annual growth rate of government expenditures (*sheet:* GCV_Growth, *data area:* b3:t6)
- Annual growth rate of expected investments (*sheet:* exo_stgr_new, *data area:* b2:v160)
- Social time preference (*sheet:* exo_stp_new, *data area:* b2:u5)
- Total factor productivity (*sheet:* exo_tfp, *data area:* b2:v160)
- Autonomous energy productivity (*sheet:* AEEI, *data area:* b2:t5 and b8:t11)
- Labour productivity (*sheet:* Labor_productivity, *data area:* bj2:cb5)
- Total factor productivity in power generation technologies (*sheet:* LCOE_tfp, *data area:* b2:t35)
- Power generation mix (*sheet:* PG_Shares, *data area:* b2:t38)
- Marginal abatement cost parameter (*sheet:* MACC, *data area:* b2:u182)

Figure 16: Baseline_Assumptions.xlsx file



			RDIM	CDIM	DIM	Links
par	pop_rates	pop_rates!b3:t6	1	1	2	Go to pop_rates
par	working_age	working_age!b3:t6	1	1	2	Go to working_age
par	new_lbfrc	labour_force!w3:aq18	2	1	3	Go to Labour Force
par	new_unrt	employment!as3:bm18	2	1	3	Go to employment
par	gpresf	Prices!b8:t9	1	1	2	Go to Prices
par	exo_gdp_growth	GDP_Growth!b3:t6	1	1	2	Go to GDP growth
par	exo_gcv_growth	GCV_Growth!b3:t6	1	1	2	Go to GCV growth
par	world_index	world_index!b2:t3	0	1	1	Go to world index
par	world_price_index	world_index!b7:t8	0	1	1	Go to world index
par	exo_stgr_new	exo_stgr_new!b2	2	1	3	Go to STGR
par	exo_stp_new	exo_stp_new!b2	1	1	2	Go to STP
par	exo_tfp	exo_tfp!b2:v10000	2	1	3	Go to TFP
par	exo_AEEI_f	AEEI!b2:t5	1	1	2	Go to AEEI
par	exo_AEEI_e	AEEI!b8:t11	1	1	2	Go to AEEI
par	exo_tgl	Labor_productivity!bj2:cb5	1	1	2	Go to Labour Productivity
par	LCOE_tfp	LCOE_tfp!b2	2	1	3	Go to LCOE_tfp
par	PGREF_Shares	PG_Shares!b2	2	1	3	Go to PG_Shares
par	MACC	MACC!b2	3	1	4	Go to MACC

The exogenous assumptions are loaded in the Baseline in the file: BASELINE.gms stored at the …\GEMSCEN\REFERENCE folder.

Baseline with endogenous instruments

In order to construct the baseline a sophisticated tool (GEM-E3-SI-Baseline) is used. This tool calculates endogenously the necessary values for the key exogenous variables of the model (technical progress, saving rate, investment adjustments) in order to achieve exogenously specified economic targets. The tool adopts a minimum distance approach where instruments values are selected within a range of plausible values minimizing the distance between targets and the resulting economic variables. The methodology of constructing the GEM-E3-SI baseline respects the logic and structure as well as the dynamic properties of the GEM-E3-SI model and therefore maintains consistency while allowing for great flexibility on target choices and their hierarchy, as well as calibration instruments. It involves the use of a tool which is encoded in GAMS – the GEM-E3-SI-Baseline tool.

$$G(x \perp s) = 0$$

The above equation is the symbolic representation of the entire GEM-E3-SI model where G(.) is the complete set of its equations and **x** an n-dimensional column vector containing all its endogenous variables, while **s** is a vector representing parameters that can be used as instruments, for developing the Baseline. The control variables **s** represent parameters of the GEM-E3-SI model such as embodied and disembodied factor productivities, habit parameters in demand functions, exogenous parameters on resource availability (e.g. active population), income distribution parameters, risk premium parameters, structural shifts in technology or other input uptake and other parameters which normally define inequality constraints. The tool involves a goal programming model which solves the following program:

$$minx,s\ w'(u1 + u2)$$

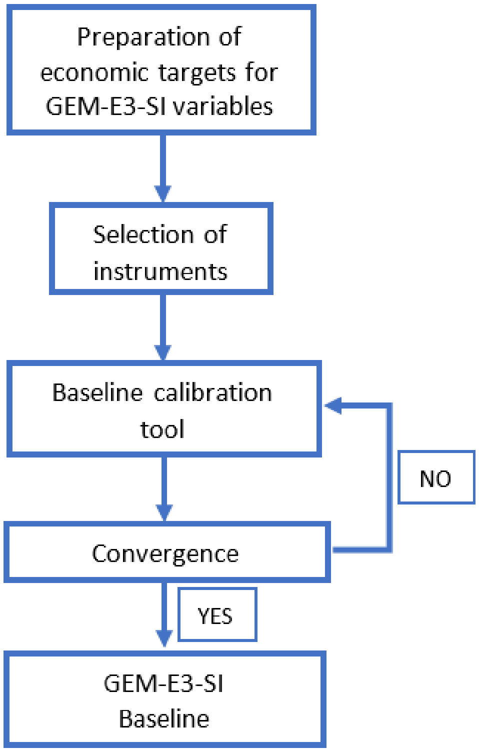
$$s.t.\ A\dot{x} + B\dot{s} = b$$

$$\dot{x} + u1 - u2 = \dot{y}$$

where: $u1 \geq 0$, $u2 \geq 0$, $\dot{x} \in \Re n$, $zl \leq \dot{s} \leq zh$, y is an n x 1 vector of target variables and w is an n x 1 vector mapping the importance of getting close to growth for a given target variable. $\boldsymbol{zl}$ and $\boldsymbol{zh}$ are vectors of lower and upper bounds defining permissible ranges for the control variables (parameters of the model).

The target variables are user-defined. Those that are of no interest as targets, can be featured with a w value equal to zero. The number of instruments used should be equal to the number of targets included to avoid dual degeneracy (multiple optima) and infeasibilities. After having established the values of the target variables, decided on the instruments to be used in order to meet the targets (as well as any restrictions concerning them) and having decided on their relative importance, the procedure then involves two iteration phases which are performed successively. The iterative procedure to construct the baseline is presented in the figure below:

Figure 17: Baseline procedure



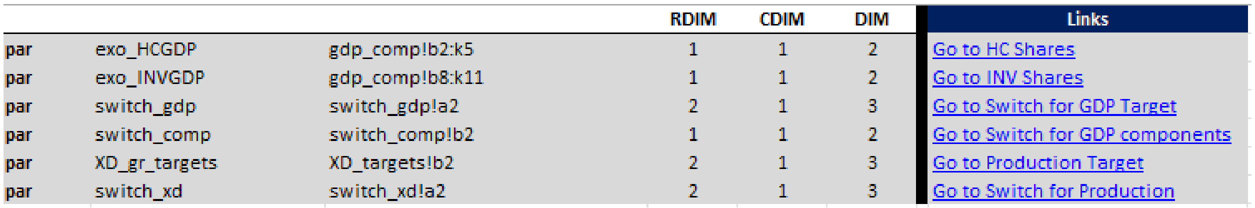
By setting *equ_base = "1"* in the M00_start.gms (stored at …\GEMMOD\ folder) the model runs with the endogenous instruments. An instrument per each endogenous target is required. The variable tfp_gdp is used as an instrument for the GDP annual growth rate, the add_stp for the share of private consumption to GDP, the add_stgr for the share of investments to GDP and the tfp_xd for the annual growth rate of sectoral production.

Different switches that allow the user to activate or disactivate the endogenous targets are used. The user can activate (=1) or disactivate (=0) the targets by setting the value of the following switches:

- switch_gdp for the annual growth rate of GDP target
- switch_comp for the share of private consumption and investments to GDP targets
- switch_xd for the annual growth rate of sectoral production

The switches can be found in the excel file: Baseline_Assumptions.xlsx at the respective sheets (), and loaded in the Baseline in the file: Endogenous_Targets.gms stored at …\GEMSCEN\REFERENCE folder.

Figure 18: Baseline_Assumptions.xlsx file – endogenous procedure



			RDIM	CDIM	DIM	Links
par	exo_HCGDP	gdp_comp!b2:k5	1	1	2	Go to HC Shares
par	exo_INVGDP	gdp_comp!b8:k11	1	1	2	Go to INV Shares
par	switch_gdp	switch_gdp!a2	2	1	3	Go to Switch for GDP Target
par	switch_comp	switch_comp!b2	1	1	2	Go to Switch for GDP components
par	XD_gr_targets	XD_targets!b2	2	1	3	Go to Production Target
par	switch_xd	switch_xd!a2	2	1	3	Go to Switch for Production

The user can exogenously define the following targets in the Baseline_Assumptions.xlsx:

- Annual growth rate of GDP (*sheet:* GDP_Growth, *data area:* b3:t6)
- Share of private consumption to GDP (*sheet:* gdp_comp, *data area:* b2:k5)
- The share of investments to GDP (*sheet:* gdp_comp, *data area:* b8:k11)
- Sectoral production annual growth rate (*sheet:* XD_targets, *data area:* b2:k40)

Once the endogenous instruments are computed they are stored in excel file Baseline_Assumptions.xlsx by updating / overwriting the exogenous parameters exo_tfp, stp and stgr that are used as an input to the GEM-E3-SI model.

Warning: It is important the file Baseline_Assumptions.xlsx to be closed in the endogenous Baseline run to allow the model to overwrite the key exogenous parameters.

Tip: Having finalized the Baseline, by using the endogenous Baseline procedure, it is recommended the user to replicate the Baseline results by using the exogenous instruments approach. That is to set *equ_base* = *"0"* in the M00_start.gms and re-run the Baseline. The results should be the same.

Scenario template

A scenario template has been developed to allow the user to run key policy scenarios without the need of developing extensive code in GAMS. The scenario template includes the following sections:

- Environmental assumptions
- Government Budget assumptions
- Renewable assumptions
- Energy Efficiency assumptions
- Power module assumptions

Environmental assumptions

The scenario template allows the user to apply either an exogenous carbon tax or an endogenous GHG emission target to specific sectors, countries, type of GHG emissions and time. The user should first define a carbon club and then to apply the exogenous carbon tax or the respective GHG target.

In the sheet SECTORAL_CLUBS the user defines a club by putting the number 1 in the data area of the following mappings:

- mapclub_countries (*data area:* c3:ad6) to add a country

- mapclub_activities (*data area:* c10:ad60) to add a sector
- mapclub_h (*data area:* d63:ad64) to add household
- mapclub_emissions (*data area:* c68:ad75) to add different type of GHG emissions
- mapclub_time (*data area:* c79:ad97) to add the time dimension

Subsequently, the user need to apply one of the following options:

- In the sheet CARBON_TAX (*data area:* c3:u30) the user can define an exogenous tax for each club defined, the parameter ctax_exo.
- In the sheet TARGET_GHG_BASELINE (*data area:* c3:u30) the user can define an endogenous GHG target as % change of the Baseline for each club defined, the parameter GHGtarget_base_exo.
- In the sheet TARGET_GHG_BYEAR (*data area:* c3:u30) the user can define an endogenous GHG target as % change of the base year for each club defined, the parameter GHGtarget_byear_exo.

Based on the user selection the GAMS code written in the *%NameScenario%.gms* activates either the switches *swtxexobr* and *swtxexoh* for a scenario with exogenous carbon tax or the switches *swclubbr* and *swclubh* for a scenario with endogenous GHG target.

In the case of the endogenous GHG target the user should select within the file *%NameScenario%.gms* the value of the switch: *sw_target_ref* (1: for a target based on the base year, 2: for a target based on the Baseline).

Government Budget assumptions

The scenario template allows the user to select in the sheet: RECYCLING different recycling options by using a share parameter: *recscheme* (*data area:* b8:u20). This parameters enables an instrument or a mix of instruments to ensure that the Government Budget as % of GDP is the same as in the Baseline scenario.

Depending of the choice, the following recycling options are used to affect either the government revenues or the government expenditures:

- recscheme = 0, corresponds to free Government Budget
- recscheme(“HT”) = 1, enables a lump sum transfer to the household
- recscheme(“SS”) = 1, enables a change in the tax rate of the employers social security contribution
- recscheme(“GT”) = 1 enables a change in the tax rate of the general taxation (indirect taxes)
- recscheme(“PS”) = 1, enables a change in the production subsidies

The user can select a mix of the above instruments (i.e., recscheme(“SS”) = 0.5 or 50% and recscheme(“GT”) = 0.5 or 50%).

The change in the instrument selected for each country is applied uniformly in the economy (i.e., to all sectors, to all occupation categories etc.). Taxes and subsidies that focuses on specific sectors should be applied by the user by writing the appropriate GAMS code in the *%NameScenario%.gms*.

Renewable assumptions

Renewable assumptions can be introduced by the user exogenously by affecting the electrification of the sectors or/and the shares of the power generation technologies used in the power sector.

In the sheet: ELECTRIFICATION of the scenario template, the user defines the share of electricity to the energy mix for specific sectors and consumption by purpose categories.

The user use the initial values of the shares of the firms and households electrification applied in the Baseline and then to apply exogenous assumptions to change of the electrification in the scenario (*data area:* c2:j4 for households and c7:j28 for firms).

The parameters electrification_firms and electrification_hh are defined in the EPIREF.gms and inform the user about the shares of electrification assumed in the Baseline. The values of these parameters should be used to update the scenario template in case of a new Baseline run.

The change in the electrification in a scenario is activated by using the switches: *sw_elec_F* for firms and *sw_elec_H* for households. In the *%NameScenario%.gms* the user can activate the assumptions regarding the electrification by setting the value of the switches equal to one.

Finally, in the sheet: RES_Targets the user can set exogenously the power mix (*data area:* c12:j24) and the associated capacity investments (*data area:* m12:t24).

Energy Efficiency assumptions

The scenario template allows the user to exogenously assume the energy efficiency expenditures and the associated energy savings. In the sheet: EE_Targets, the energy efficiency expenditures for firms' (*data area:* c10:j31) and for households' (*data area:* d33:j34) renovation, and the expenditures for energy efficient equipment in firms (*data area:* m10:t31) and households (*data area:* n33:t34) can be loaded by the user in the scenario.

The user has the option to set the energy efficiency gains exogenously or to enable an energy efficiency curve that links the cumulative energy efficiency expenditures with energy savings. The switches f_select_renov, f_select_equip, h_select_renov, h_select_equip, allow the user to activate or not the semi-endogenous computation of the energy efficiency gains.

By setting the value of the switches f_select_renov, f_select_equip, h_select_renov, h_select_equip equal to zero, the user have to assume exogenously the energy efficiency gains. In the sheet: EE_Targets the users' assumptions regarding the energy efficiency gains for firms' (*data area:* c37:j58) and for households' (*data area:* d60:j61) renovation, and the efficiency gains from the energy efficient equipment in firms (*data area:* m37:t58) and in households (*data area:* n60:t61) can be loaded in the scenario.

By setting the value of the switches f_select_renov, f_select_equip, h_select_renov, h_select_equip equal to one, the user enables the semi-endogenous computation of the energy efficiency gains which are linked, via the energy efficiency curve, with the cumulative expenditures of the firms and households for renovation and energy efficient equipment, respectively.

Furthermore, a share parameter, that allows the user to select the share of household's energy efficiency expenditures that is financed by their own income has been added. By selecting the value of the sh_finance equal to one, it is assumed that the household self-finances their energy efficiency expenditures. A value of the parameter sh_finance equal to zero assumes that the energy efficiency expenditures are fully-financed by the Government Budget.

Energy Power module assumptions

The scenario template allows the user to define the exogenous investment in capacity that will be considered in the power model run if a soft-link approach used (see next section). In the sheet:

Exogenous_INV (*data area:* b2:ag6) the user can add investment per MW for the 4 different power generation technologies of the power module (Fossil, RES, Nuclear and Hydro).

Power sector

Objective

The power module has been developed to extent the substitution possibilities of the power sector in the GEM-E3-SI model and allows an evaluation of investments needs based on technoeconomic assumptions used for each power generation technology.

Options of the simulation of the power sector

In the GEM-E3-SI model four options are available for the simulation of the power sector:

- Exogenous assumptions by the user for the power mix and endogenous decision for the associated investment by power generation technology.
- Exogenous assumptions by the user for the power mix and for the associated investment by power generation technology.
- Endogenous decision via a Weibull function for the power mix and for the associated investment by power generation technology.
- Soft-link approach with a power module

Caution: The user should always compare scenarios with the respective baseline that have been simulated by using the same option in the simulation of the power sector. The first option is used as default option for the Baseline. The user can either update the Baseline if a different option is selected or run the Baseline as a scenario run and use this scenario for comparison purposes.

The default option in the GEM-E3-SI model is to set exogenously the shares of power generation technologies and the associated investment to be decided endogenously by the firms' investment decision in the model.

Under this option the user has to set the power generation mix in the Baseline_Assumptions.xlsx (*sheet:* PG_Shares, *data area:* b2:t38) for the Baseline run, and in the sheet RES_Targets (*data area:* c12:j24) in the scenario template for each scenario run. This option requires by the user to set the switch swxdiotec equal to 0, the switch user_defined_dio equal to 1, the switch swtec equal to 0, and the switch power_link equal to 0 in the *%NameScenario%.gms*.

In the second option, the user has to set exogenously both the power mix and the investment related to the change in the power mix. To do this, the user should add in the scenario template in the sheet RES_Targets the power mix (*data area:* c12:j24) and the associated capacity investments (*data area:* m12:t24). This option requires by the user to set the switch swxdiotec equal to 0, the switch user_defined_dio equal to 1, the switch swtec equal to 1, and the switch power_link equal to 0 in the *%NameScenario%.gms*.

In the third option, both the power mix and the investment related to the change in the power mix are determined by the model. This option requires by the user to set the switch swxdiotec equal to 1, and the switch power_link equal to zero in the *%NameScenario%.gms*.

Finally, in the fourth option a soft-link approach is established and an iterative procedure should be followed by the user (see section 0). This option requires by the user to set the switch power_link equal to one in the *%NameScenario%.gms,* then the other switched are selected automatic by the code.

Table 9 summarizes the different choices of the switches that the user can use under each option.

Table 9: Switches selection under different options of simulation of the power sector

		Power generation mix		
		Defined by the user	**Computed by the model**	**Soft-link approach**
Investments by power generation technology	**Defined by the user**	**Option 2** swxdiotec = 0 user_defined_dio = 1 swtec = 1 power_link = 0		
	Computed by the model	**Option 1** swxdiotec = 0 user_defined_dio = 1 swtec = 0 power_link = 0	**Option 3** swxdiotec = 1 user_defined_dio = 0 swtec = 1 power_link = 0	
	Soft-link approach			**Option 4** power_link = 1 **Automatic selection by the code:** swxdiotec = 0 swtec = 1

Soft-link with the power model

An iterative procedure is followed by the user under the soft-link approach of the GEM-E3-SI model with the power model. In each iteration, the power model will use as input the electricity demand provided by the GEM-E3-SI model and provide as result to the GEM-E3-SI model the power mix and the associated investments for each power generation technology. The GEM-E3-SI model will use as input the power mix and the associated investments by power generation technology provided by the power model and provide as result the electricity demand to the power model.

The iteration procedure should stop if in two subsequent runs the % change of the electricity demand do not differ much. A convergence criteria, the maximum absolute distance in the electricity demand in time in two subsequent runs to be lower than 0.1%, is recommended.

Under the soft-link approach option, the user should follow the steps below:

1. Design the scenario in the GEM-E3-SI model and select the switches as described in Option 4 in previous subsection.
2. Run the scenario with the GEM-E3-SI interface
3. Check the convergence criteria (parameter Elec_convergence in the *%NameScenario%.gdx*)
4. Repeat steps 2 - 3 until a convergence criteria is met.

When the user press the button to run the scenario in the GEM-E3-SI interface: the power model runs by including the file: 00_PG_Module.gms stored at: …\GEMSCEN\SCENARIO\SCENARIO_INSTRUMENTS\. In the first iteration the electricity demand of the Baseline[13] is used. The main output of the power model is the Power_%scen%.gdx file stored at …\GEMSCEN\SCENARIO\SCENARIO_INSTRUMENTS\ where %scen% corresponds to the scenario name defined by the user.

Once the power model ends, the GEM-E3-SI model, by having the switch the power_link = 1 in the *%NameScenario%.gms*, activates the link with the power model and loads as input the power mix and the associated investments by each power generation technology from the Power_%scen%.gdx.

Once the GEM-E3-SI model ends, the GEME3SI_%scen%.gdx file is produced (stored at the folder directory …\GEMSCEN\SCENARIO\SCENARIO_INSTRUMENTS\). This file contains the electricity demand and the ratio of the "new electricity demand[14]" with the "old electricity demand[15]".

The user should check if the ratio between the two subsequent electricity demand (parameter: *Elec_convergence*) satisfy the convergence criteria and decide if a new iteration is required.

It should be noted that the power model and the GEM-E3-SI model have different modelling frameworks (i.e., investment decision in the power model is based on the full foresight assumption whereas in the GEM-E3-SI model the myopic expectations assumption is used). Diagnostic scenarios have implemented to test and check the speed of convergence under different scenarios. It is found that the scenarios with exogenous carbon tax has much faster speed of convergence and without any convergence issues than scenarios with endogenous GHG target. Thus, our recommendation is to run the power link approach in scenarios with exogenous carbon tax rather than endogenous GHG targets.

Tip

An ambitious endogenous GHG target may result a high carbon price under the assumption of no substitution in the power generation mix (i.e., exogenous shares in power generation mix). The high carbon price that will be introduced as input to power model may result high changes in the power mix from fossil fuel based technologies to green technologies. This greener power mix may lead to very low carbon price when it is used in GEM-E3-SI model and so on. Depending on the sensitiveness of the models to the change in the carbon price, the speed of convergence may be very low or not exist.

An approach to overcome this convergence issue is the use of the dichotomy approach. That is, to apply in each step not the 100% of the change in the input used by the models between the two subsequent runs, but only the 50% of the distance. Depending on the sensitiveness of the models with respect to this change, this 50% share in the distance may be appropriate to be reduced to 30% or 20%. The key idea of this approach is to apply a change by having the correct direction (i.e., an increase in the carbon price is required to meet the GHG target) but using a lower magnitude / change in the instruments used to reduce the sensitiveness of the models with respect to this change.

Another approach to overcome convergence issues of a scenario with endogenous GHG target is to implement it by using an exogenous carbon tax. Initial values of the carbon tax can be applied and an

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[13] In case of a new Baseline in the GEM-E3-SI the user should also inform the Baseline of the power model with the electricity demand and implement the same procedure for the Baseline

[14] New electricity demand: the electricity demand as a result of the GEM-E3-SI model after the "new scenario run".

[15] Old electricity demand: the electricity demand used in the power model to provide the input for the GEM-E3-SI model before the "new scenario run".

iterative procedure via updating this values can be used to close the gap between the emissions resulted and the GHG target we need to achieve. If the sensitiveness of the model results to the change of the carbon tax is high, the dichotomy approach is recommended to be applied in the change of the carbon tax between two subsequent runs.

4 The Slovenian Baseline Scenario

Baseline assumptions on key macroeconomic aggregates

The key assumptions to develop the Slovenian baseline are:

1. Period 2022 - 2024 is based on IMAD short term projection
2. GDP projection on 2025 onwards is based on DG- ECFIN Ageing Report 2021
3. Trade openness increases steadily over time at a decreasing pace follows past trends
4. Trade surplus increases in absolute terms but decreases as percentage of GDP
5. Government expenditure as a share to GDP (17.8%) remains constant over time as it is considered to be within a sustainable range
6. Investment share to GDP remains constant

Table 10: GEM-E3-SI Baseline targets for GDP components

	Historical						**IMAD**			**Projection period**					
	2016	2017	2018	2019	2020	2021	2022	2023	2024	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
GDP	3.2%	4.8%	4.5%	3.5%	-4.3%	8.2%	5.0%	1.4%	2.6%	2.53%	2.32%	1.91%	1.39%	1.09%	1.07%
HC	4.4%	1.9%	3.5%	5.3%	-6.9%	9.5%	5.5%	0.3%	1.9%	2.73%	2.50%	2.06%	1.51%	1.19%	1.17%
INV	-3.6%	10.2%	10.2%	5.1%	-7.9%	13.7%	6.5%	2.5%	2.0%	2.53%	2.32%	1.91%	1.39%	1.09%	1.07%
GC	2.4%	0.4%	2.9%	1.8%	4.1%	5.8%	1.4%	1.7%	1.9%	2.53%	2.32%	1.91%	1.39%	1.09%	1.07%
Stock	113.0%	70.6%	20.6%	-44.5%	4.9%	41.3%	85.9%	3.7%	-3.3%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EXP	6.2%	11.1%	6.2%	4.5%	-8.6%	14.5%	5.0%	2.5%	4.7%	3.22%	2.99%	2.56%	2.02%	1.69%	1.66%
IMP	6.3%	10.7%	7.1%	4.7%	-9.6%	17.6%	6.5%	2.2%	3.8%	3.28%	3.05%	2.62%	2.07%	1.74%	1.70%

Note: GDP: Gross Domestic Product, HC: Household Consumption, INV: Investments, GC: Government expenditures, Stock: Change in Stock, EXP: Exports, IMP: Imports

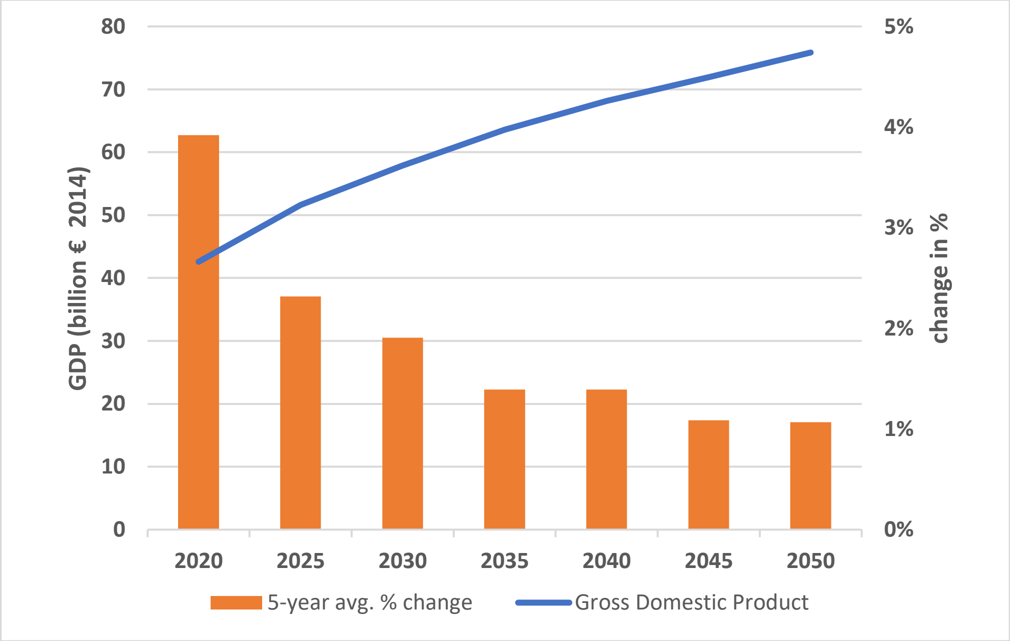
Slovenia is an export-oriented economy with a population of 2.1 million and a GDP per capita of 22.4 thousand € (2020). Since the dissolution of Yugoslavia, Slovenia has achieved greater convergence with advanced OECD economies than most of its transition peers. Between 2008 and 2013 the country suffered a double hard landing as a result of the global financial crisis and subsequent domestic banking crisis. However, thanks to structural reforms, supportive monetary conditions and improved export markets, Slovenia recovered and started growing again. Slovenia had stabilized economically and fiscally by the end of 2018, but then COVID-19 posed severe challenges, as in many economies around the globe.

The country has strong manufacturing and export links with the EU, a high standard of living compared to the rest of Eastern European countries and strong uptake in information and communications technology. In 2020 the industry & construction account for the 33.1% of GVA. Wholesale and retail trade, transport, accommodation and food services (19.3%); financial and other market services (27.1%) and public administration, defense, education, human health and social work activities (18.2%). In industry, major sources of income rely on the manufacturing of pharmaceuticals, fabricated metals, and electrical appliances.

Convergence is expected to continue over the long run, although the growth of the economy will be slower than in less developed transition states with greater catch-up potential. A poor demographic outlook and structural weaknesses, including rigid product and labour markets, are expected to constrain long-term growth. In 2021, Slovenia rose by 8.2% in real GDP, surpassing pre-pandemic levels. Exports and private consumption were the main drivers, the result of a series of COVID-19 support measures (totaling about 1% of GDP in 2022) and lower household savings rates. Economic activity remained strong in the first half of this year, with GDP growing by close to 9% year-on year, driven by strong domestic demand.

Nonetheless, Slovenia's strong post-pandemic recovery has been hit by Russia's invasion of Ukraine, skyrocketing energy prices, and supply chain bottlenecks, and GDP growth is projected to drop down to 1.5% in 2023 from 5% in 2022. The slowdown is caused by weaker external demand, and also by high inflation and greater uncertainty, which are expected to weigh on private consumption and investment growth. Despite slowing activity, labour market performance is strong leading to historically high employment and even labor shortages in some sectors, low unemployment, and stronger wage growth. In 2023, GDP growth is projected to reach 1.4% with trends seen in the second half of 2022 expected to continue in the first half of next year.

Figure 19: GDP projections



Source: GEM-E3-SI

The economy is expected to grow at a 2.3% in 2024 as inflation slowly recedes and under the assumption that no additional shocks emerge in the international environment and prices remain stable. Overall, GDP is assumed to grow by 2.8% on average (annual growth rate) in the forecast period (2022–2024) with the greatest contribution made by total factor productivity (1.5 p.p.). The contribution of capital should also increase significantly as a result of the rise in investment related to additional EU funds but will remain lower on average (at 0.7 p.p.) than in the past. Labour is expected to contribute 0.6 p.p. on average to potential growth in the forecast period, which will also be a consequence of the expected further increase in the activity rate and net inflow of foreign workers.

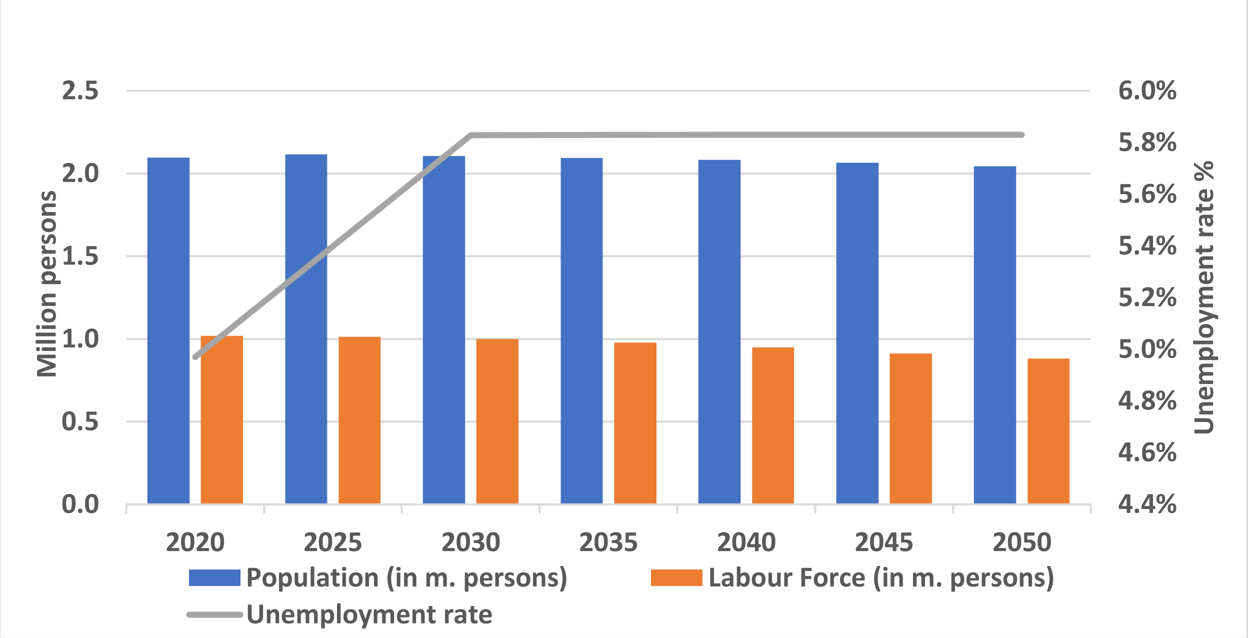
As the energy crisis deepens and economic activity in Slovenia's main trading partners decelerates, exports are expected to decline by the end of the year. Manufacturing, especially energy-intensive industries, will be negatively affected and the growth of trade in services, mainly transportation, will also slow down. A decline in private consumption, fueled by high inflation and expiry of support measures, should also be expected.

Demographic change and the ageing population represent major challenges for Slovenia. Population ageing is projected to result in a smaller and older workforce, while the number of pensioners increases. Financing the fiscal costs of population ageing requires containing the rise in ageing-related spending in the pension, health and long-term care systems.

The workforce drops from 1 million people in 2020-2030 to 880 thousand in 2030-2050. Meanwhile unemployment rate is between 5% and 6% in the course of the projection period. In 2022, employment will continue to increase, and unemployment will continue to decline. Until 2024 the slowdown in economic activity and labour shortages are expected to lower employment intensity.

The demand for labour will continue to be a pull factor for attracting foreign workers. Nevertheless, the population aged 15–64, which makes up the bulk of the active labour force, will continue to decline and demographic trends will increasingly restrict the growth of value added.

Figure 20: Population, labour force and unemployment rate



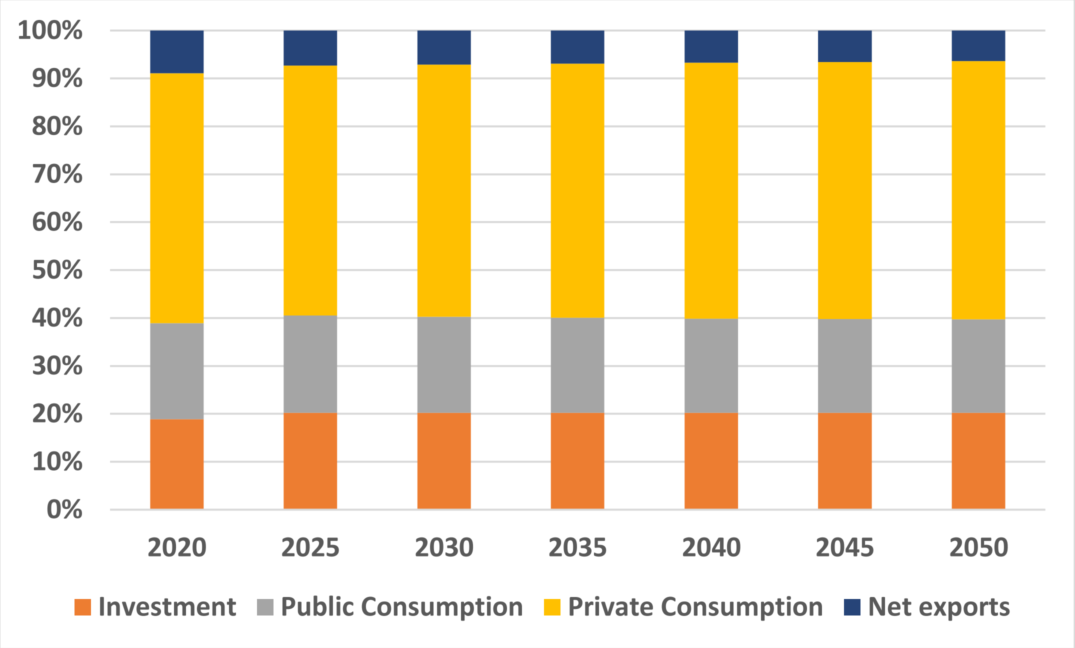
Source: GEM-E3-SI

Baseline, results

GDP components

Between 2025 and 2035 GDP is projected to grow by 2%, and between 2035 and 2050 by 1%. The macroeconomic components of Slovenian GDP are projected to change only marginally by 2050. In the short term, under conditions of high uncertainty, high prices and rising interest rates, investment is not projected to increase significantly. Throughout the projection period, GDP composition continues to be dominated by private consumption, while public consumption, investment and net exports remain stable.

Figure 21: Components of GDP

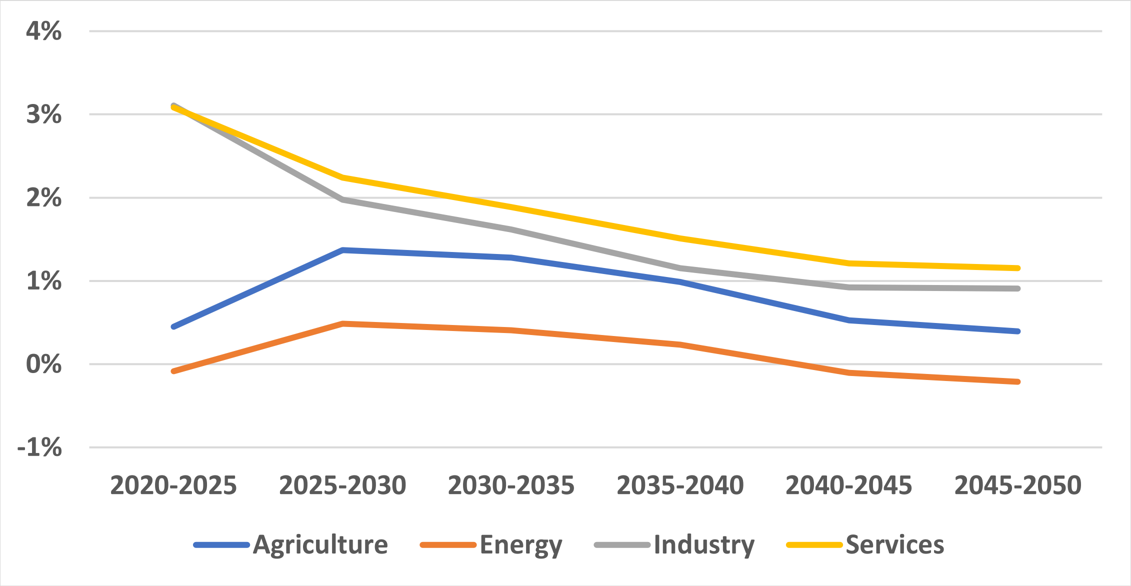


Source: GEM-E3-SI

Sectoral results

The services sector dominates, generating slightly over 77.7 billion € of value added in 2050, followed by industry that generates almost 74.1 billion €. Pharmaceuticals, equipment goods and construction are industrial sectors that record significant growth while market and non-market services are driving improvements in services sectorial activity until 2050. On the other hand, the contribution of energy and agriculture is small, and does not change until the end of the projection period.

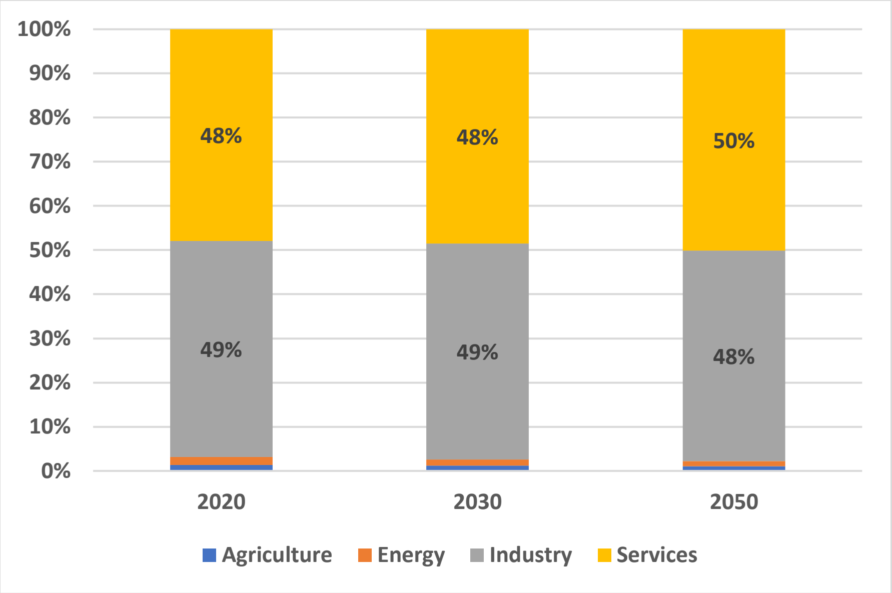
Figure 22: Change in sectoral GVA (%)



Source: GEM-E3-SI

Energy intensive industries such as ferrous and non-ferrous metals along with non-metallic minerals are projected to grow very modestly.

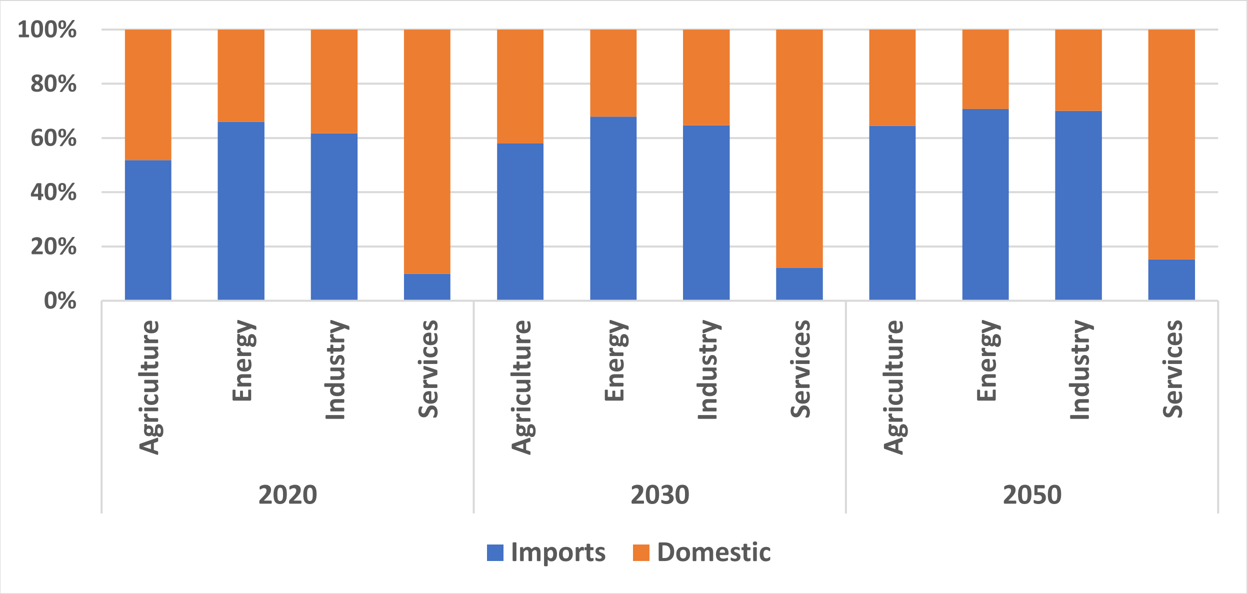
Figure 23: Shares in total GVA (%)



Source: GEM-E3-SI

Figure 24 and Figure 25 show the importance of each sector in the domestic market. The services have the highest domestic contribution across sectors and the energy sector the highest import share.

Figure 24: Domestic use vs imports



Source: GEM-E3-SI

Industrial products are directed mostly to the external sector with chemicals, pharmaceuticals, equipment and electronic goods to have the highest exports to production share.

Figure 25: Domestic use vs exports

Source: GEM-E3-SI

5 Diagnostic and policy scenarios

In order to illustrate the model properties a series of scenarios have been quantified with the GEM-E3-SI model. Two sets of scenarios are quantified, the diagnostic scenarios that help the user to identify the main parameters of the model and their importance in the model results and the policy scenarios that help the user to quantify and analyze the results of practical policy examples.

Below we provide the key assumptions of the scenarios, the key channels through which the economy is affected and their impact on a series of key indicators. The key graphs used for the analysis of the results can be found in the excel files: Diagnostics_Graphs.xlsx and Policies_Graphs.xlsx stored at: …\GEMSCEN\SCENARIO\REPORTS folder.

Diagnostic scenarios

The diagnostic scenarios focuses on the parameters that play an important role in the Baseline projections. Most of these parameters remain unchanged in the scenario runs. In each scenario, the main assumptions and a short analysis of the results are provided. The diagnostic scenarios simulated are:

1. Increase in labor force (BASE-LFRC)
2. Increase in Labour Productivity (BASE-TGL)
3. Increase in energy efficiency in firms (BASE-TGE)
4. Increase in total factor productivity (BASE-TFP)
5. Increase in Investment (BASE_STGR)
6. Increase in Excise taxes (BASE_TXIT)
7. Increase in VAT (BASE_VAT)
8. Increase in Direct Taxation (BASE-DT)
9. Increase in employers social security contributions (BASE-SS)

BASE-LFRC

In this scenario it is assumed that an increase in participation rates will increase the labour force of the economy by 10% in the period 2025 – 2050. The parameter in the model that corresponds to the labour force by occupation is the TotLabFrc. The GAMS code required to be added in the scenario template to increase the labour force after the year 2020 is:

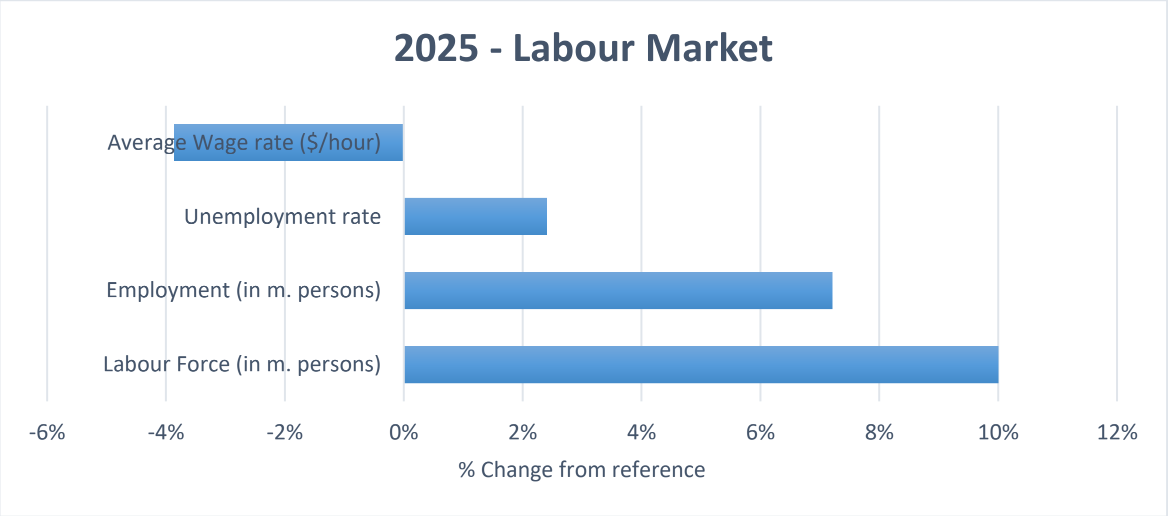
```
TotLabFrc(sk_type,"SVN",rtime)$(rtime.val > 2020) = 1.1 * TotLabFrc(sk_type,"SVN",rtime);
```

The channels through which the economy is affected are the following:

- Increase of Labour supply
- Higher Labour supply decreases the unit cost of labour
- Lower unit cost of labour decreases the unit cost of production
- Lower unit cost of production increases the demand of products
- Higher demand for products increases the demand for all factors of production (i.e., capital)
- Higher demand for capital increases the unit cost of capital
- Due to the limited substitution possibilities of labour with capital the increase in labour force will not lead to exactly the same increase in effective labour supply

Figure 26 shows that the increase in the labour supply by 10%, as compared with the reference case, increases the employment by 7.2%, the unemployment rate by 2.4% and decreases the unit cost of labour by 3.9%.

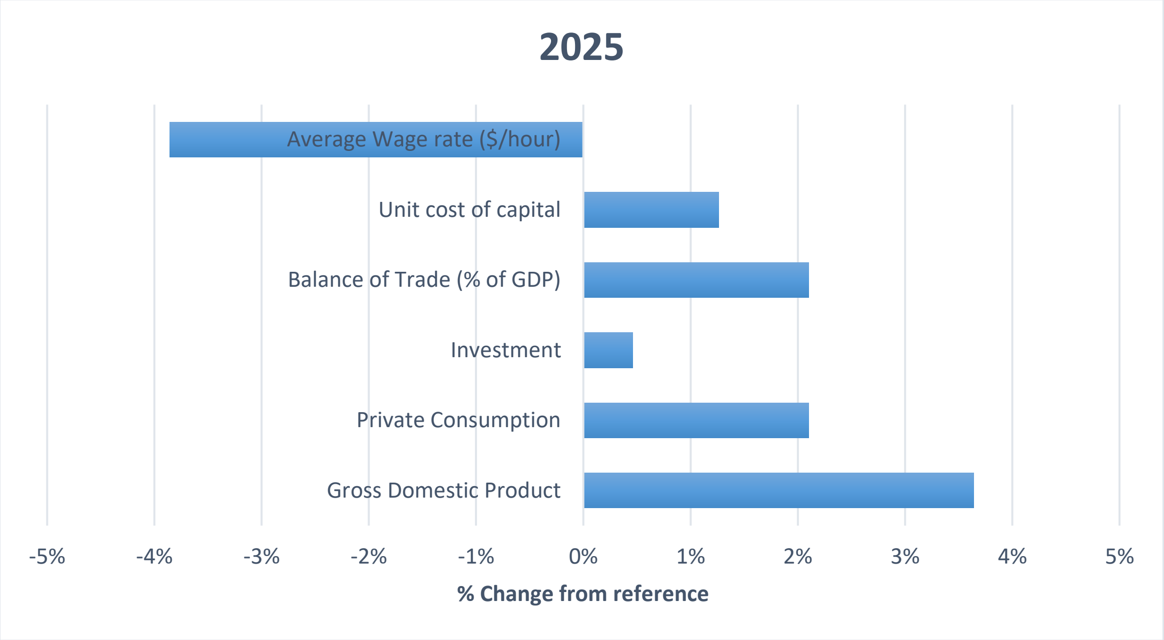
Figure 26: Labour market – BASE-LFRC



Source: GEM-E3-SI. Note: unemployment rate is presented as change in p.p. as compared to the reference.

Figure 27 Shows that the unchanged supply of capital stock in 2025 and the limited substitution possibilities between labour and capital imply an increase in the unit cost of capital, by 1.3%, and a moderate positive impact in GDP, by 3.6%. At the components of GDP, the total household income increases as a result of the additional employment resulting an increase in private consumption. The increase in the unit cost of capital gives a signal to the investors to increase their investments. The lower unit cost of production implies competitiveness advantages as compared with the external sector which improves the balance of trade.

Figure 27: Key macroeconomic aggregates – BASE-LFRC



Source: GEM-E3-SI

BASE-TGL

In this scenario it is assumed that learning by doing increases labour productivity by 1% in the period 2025 – 2050. The parameter in the model that corresponds to the labour productivity by occupation is the tgl. The GAMS code[16] required to be added in the scenario template to increase the labour productivity after the year 2020 is:

```
TGL(sk_type,br,"SVN",rtime)$(rtime.val > 2020)  = TGL(sk_type,br,"SVN",rtime) + log(1 + 0.01);
```

The channels through which the economy is affected are the following:

- Increase the productive capacity of the firms
- Higher productive capacity decreases the unit cost of production
- Lower unit cost of production increases the demand of products
- Higher demand for products increases the demand for all factors of production (i.e., labour and capital)
- Higher demand for capital and labour increases their unit costs
- Higher real wage increases the effective labour supply

Figure 28 shows that the technical progress in labour in 2025 decreases the unit cost of production and increases the demand for all factor of production. In this scenario there is an increase in GDP by 0.6% depending on the share of labour in the production process. At the components of GDP, the total household income increases as a result of the additional employment and the higher wage rate, resulting an increase in private consumption. The increase in the unit cost of capital gives a signal to the investors to increase their investments. The lower unit cost of production implies competitiveness advantages as

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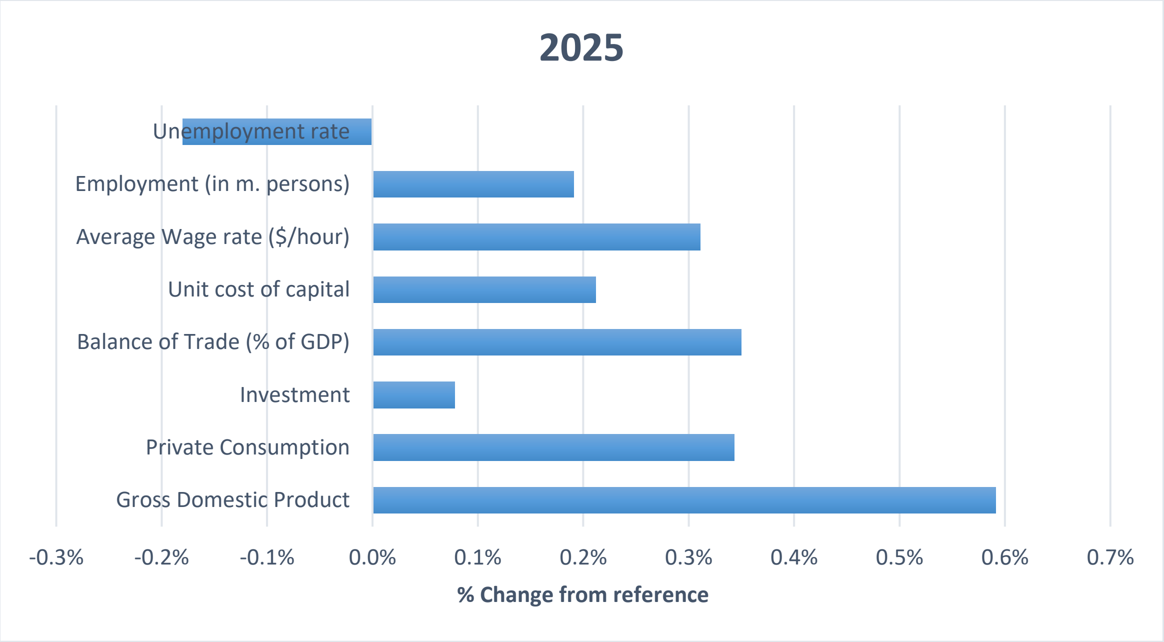
[16] Please note that the labour productivity follows an exponential mathematical form in the CES production function, therefore: $e^{\text{tgl}+\log(1+0.01)} = 1.01 \cdot e^{\text{tgl}}$

compared with the external sector which improves the balance of trade. Higher real wage increases the effective labour supply and decreases the unemployment rate.

Figure 28: Key macroeconomic aggregates – BASE-TGL



Source: GEM-E3-SI. Note: unemployment rate is presented as change in p.p. as compared to the reference.

BASE-TGE

In this scenario it is assumed an increase in the firms' energy efficiency by 1% in the period 2025 – 2050. The parameter in the model that corresponds to the energy productivity in firms is the tge. The GAMS code[17] required to be added in the scenario template to increase the energy productivity after the year 2020 is:

```
TGE(pren,br,"SVN",rtime)$(rtime.val > 2020)  = TGE(pren,br,"SVN",rtime) + log(1 + 0.01);
```

The channels through which the economy is affected are the following:

- ✓ Increase the productive capacity of the firms
- ✓ Higher productive capacity decreases the unit cost of production
- ✓ Lower unit cost of production increases the demand of products
- ✓ Higher demand for products increases the demand for all factors of production (i.e., labour and capital)
- ✓ Higher demand for capital and labour increases their unit costs

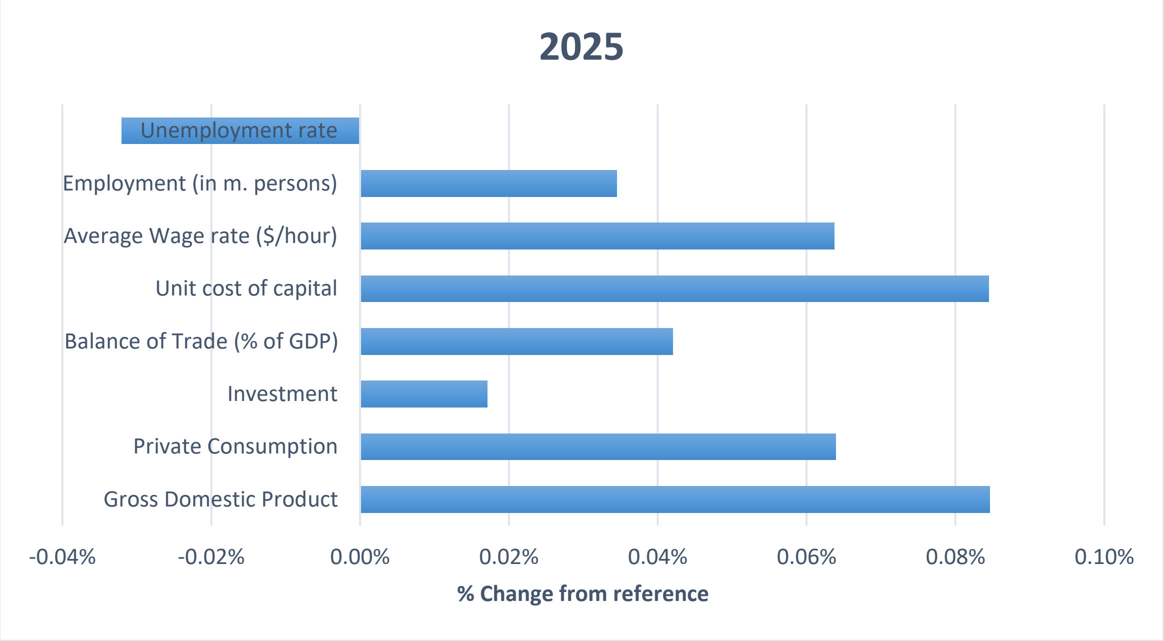
Figure 29 shows that the technical progress in energy in 2025 decreases the unit cost of production and increases the demand for all factor of production. In this scenario there is an increase in GDP by 0.6% compared to reference depending on the share of energy in the production process. At the components of GDP, the total household income increases as a result of the additional employment and the higher

---

[17] Please note that the energy productivity follows an exponential mathematical form in the CES production function, therefore: $e^{\text{tge}+\log(1+0.01)} = 1.01 \cdot e^{\text{tge}}$

wage rate, resulting an increase in private consumption. The increase in the unit cost of capital gives a signal to the investors to increase their investments. The lower unit cost of production implies competitiveness advantages as compared with the external sector which improves the balance of trade. Higher real wage increases the effective labour supply and decreases the unemployment rate. Similar results as compared to the BASE-TGL scenario but at a much lower scale as the energy share in the production process is much lower than the labour share.

Figure 29: Key macroeconomic aggregates – BASE-TGE



Source: GEM-E3-SI. Note: unemployment rate is presented as change in p.p. as compared to the reference.

BASE-TFP

In this scenario it is assumed an increase in the total factor productivity by 1% in the period 2025 – 2050. The parameter in the model that corresponds to the total factor productivity is the tfp and the tfpexo. The GAMS code[18] required to be added in the scenario template to increase the total factor productivity after the year 2020 is:

```
TFP(br,"SVN",rtime)$(rtime.val > 2020)  = TFP(br,"SVN",rtime) * 1.01;
```

The channels through which the economy is affected are the following:

- ✓ Increase the productive capacity of the firms
- ✓ Higher productive capacity decreases the unit cost of production
- ✓ Lower unit cost of production increases the demand of products
- ✓ Higher demand for products increases the demand for all factors of production (i.e., labour and capital)
- ✓ Higher demand for capital and labour increases their unit costs

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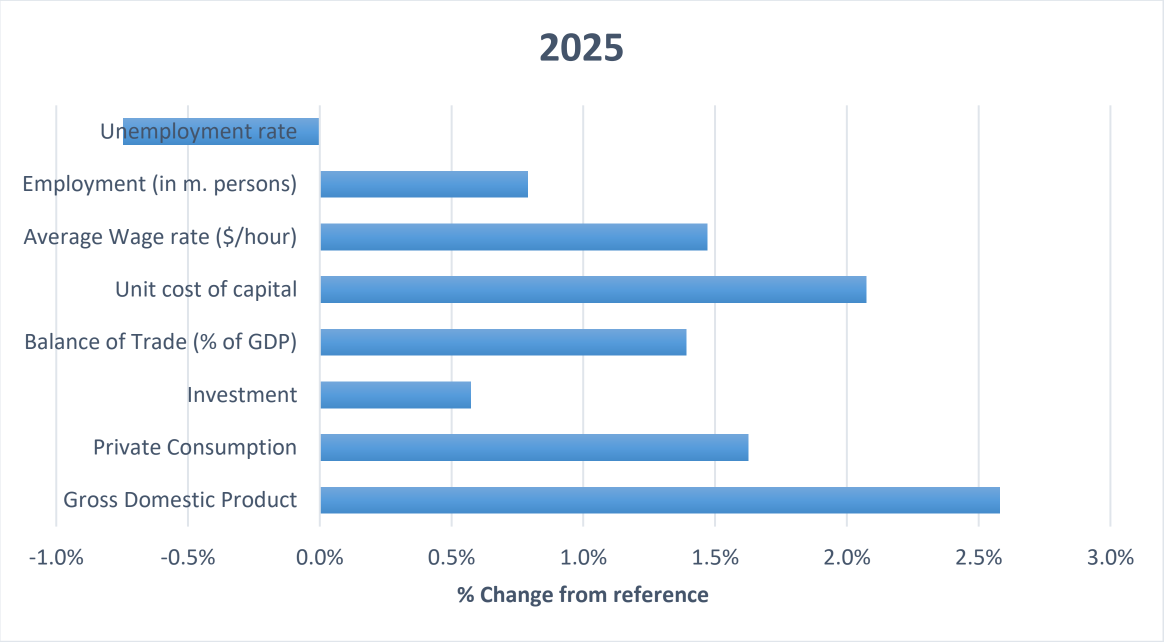
[18] Please note that the total factor productivity follows a multiplicative functional form in the CES production function.

Results are similar to the scenarios with a change in technical progress but at a higher scale. The increase in total factor productivity by 1% imply an increase in technical progress of all factors of production.

Figure 30: Key macroeconomic aggregates – BASE-TFP



Source: GEM-E3-SI. Note: unemployment rate is presented as change in p.p. as compared to the reference.

BASE-STGR

In this scenario an increase in the expected investment growth in 2025 by 5% is assumed. The parameter in the model that corresponds to the expected investment growth is the stgr. The GAMS code[19] required to be added in the scenario template to increase the expected investment growth at the year 2025 is:

```
stgr(pr,"SVN",rtime)$(rtime.val = 2025) = stgr(pr,"SVN",rtime) * 1.05;
```

The channels through which the economy is affected are the following:

- ✓ Increase the investments in 2025
- ✓ Higher demand for investment deliveries increases the demand for all factors of production (i.e., labour, capital)
- ✓ Higher demand for labour and capital increases their unit costs
- ✓ Effective labour supply increases but capital stock remain the same
- ✓ Additional investments in 2025 create capital stock for the 2030 that increases the productive capacity of the economy

Figure 31 shows that the higher expectations for investment growth increases investments in 2025. The higher demand for investment products in 2025 put a pressure to the capital and labour market increasing

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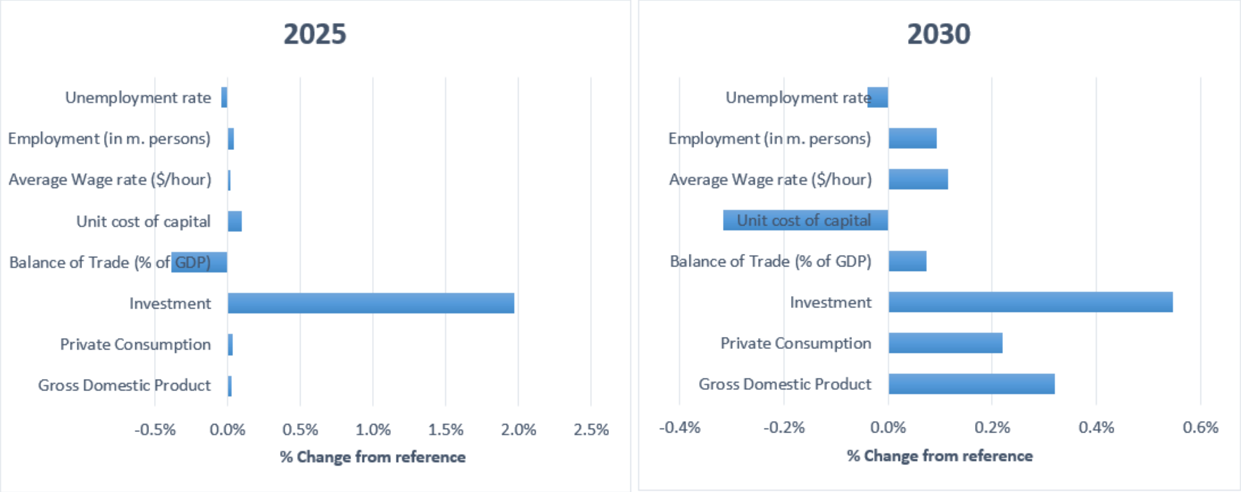
[19] Please note that the total factor productivity follows a multiplicative functional form in the investment function.

the unit cost of capital and labour, respectively. The increase in the factor costs deteriorates the trade balance resulting a minor positive impact in GDP in 2025.

In 2030 the additional capital stock created by the additional investments in the previous period decreases the unit cost of production due to the lower unit cost of capital. The additional demand for products increases the unit cost of labour and decreases unemployment rate. The additional resources, capital stock and effective labour supply, increases the productive capacity of the economy resulting an increase in GDP by 0.32% in 2030.

Figure 31: Key macroeconomic aggregates – BASE-STGR



Source: GEM-E3-SI. Note: unemployment rate is presented as change in p.p. as compared to the reference.

BASE-TXIT

In this scenario an increase in excise taxes by 10% is introduced. The corresponding model parameter for excise taxes is the *txit*. The GAMS code required to be added in the scenario template so as to increase the indirect taxes by 10% for the period 2025 – 2050 is:

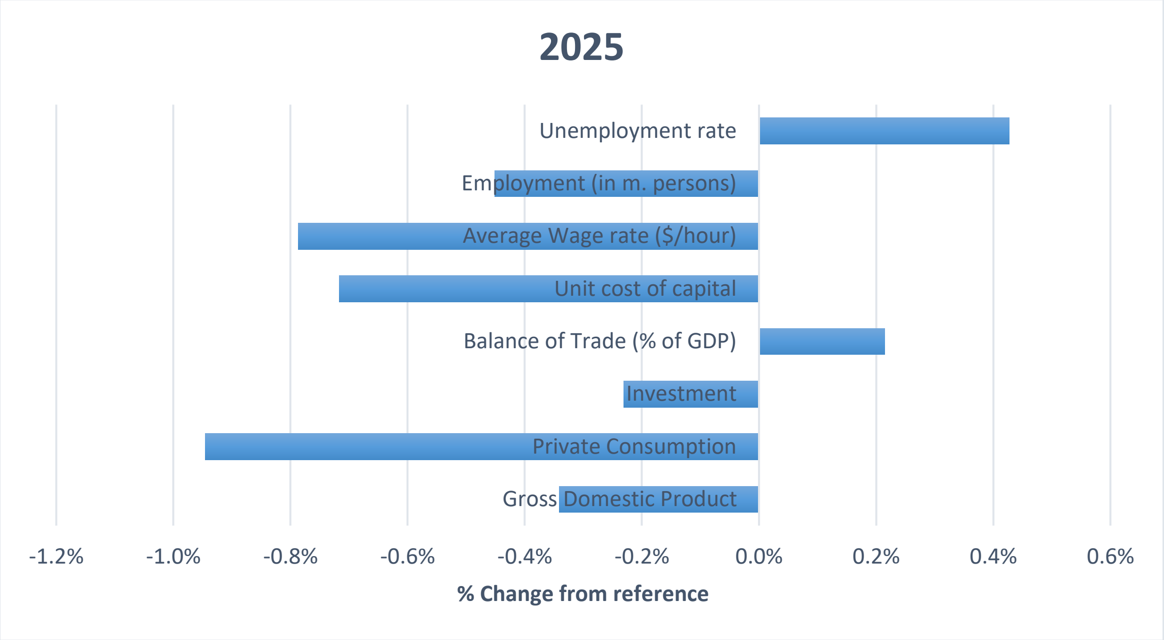
```
* Increase in Indirect Taxes
txit(pr,"SVN",rtime)$((rtime.val > 2020) and  (txit(pr,"SVN",rtime) > 0))
                   = txit(pr,"SVN",rtime) * 1.1;
```

The channels through which the economy is affected are the following:

- ✓ Increase the end-use price of products
- ✓ Higher end-use price decreases the real wage
- ✓ Lower real wage decreases the effective labour supply
- ✓ Higher end-use price decreases the demand of products
- ✓ Lower demand for products decreases the demand for all factors of production (i.e., labour and capital)
- ✓ Lower demand for capital and labour decreases their unit costs

Figure 32 shows the results on the key macroeconomic aggregates in 2025.

Figure 32: Key macroeconomic aggregates – BASE-TXIT



Source: GEM-E3-SI

BASE-VAT

In this scenario an increase in VAT rate by 10% is assumed. The corresponding model parameter for the VAT is the txvat. The GAMS code required to be added in the scenario template to increase the VAT taxes by 10% for the period 2025 – 2050 is:

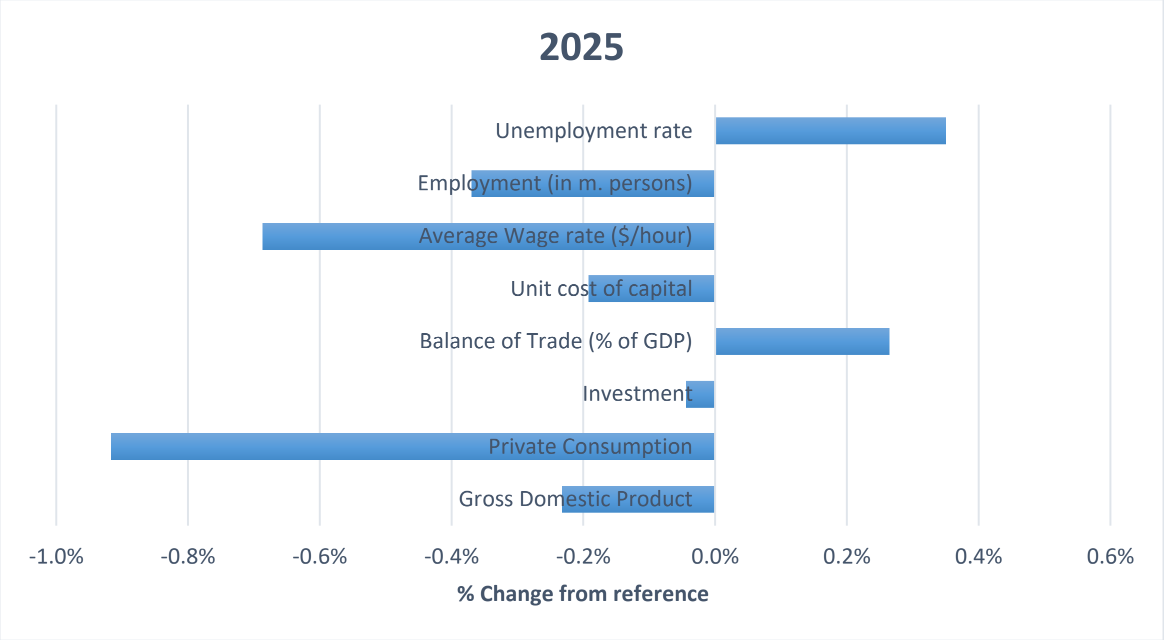
```
* Increase in VAT Taxes
txvat(pr,"SVN",rtime)$((rtime.val > 2020) and  (txvat(pr,"SVN",rtime) > 0))
                    = txvat(pr,"SVN",rtime) * 1.1;
```

The channels through which the economy is affected are the following:

- ✓ Increase the end-use price of products
- ✓ Higher end-use price decreases the real wage
- ✓ Lower real wage decreases the effective labour supply
- ✓ Higher end-use price decreases the demand of products
- ✓ Lower demand for products decreases the demand for all factors of production (i.e., labour and capital)
- ✓ Lower demand for capital and labour decreases their unit costs

Figure 33 shows the results on the key macroeconomic aggregates in 2025.

Figure 33: Key macroeconomic aggregates – BASE-VAT



Source: GEM-E3-SI

BASE-DT

In this scenario an increase in the direct taxation of households by 10% is assumed. The corresponding model parameter for the direct taxes of households is the txdirtaxh. The GAMS code required to be added in the scenario template to increase the direct taxes in households by 10% for the period 2025 – 2050 is:

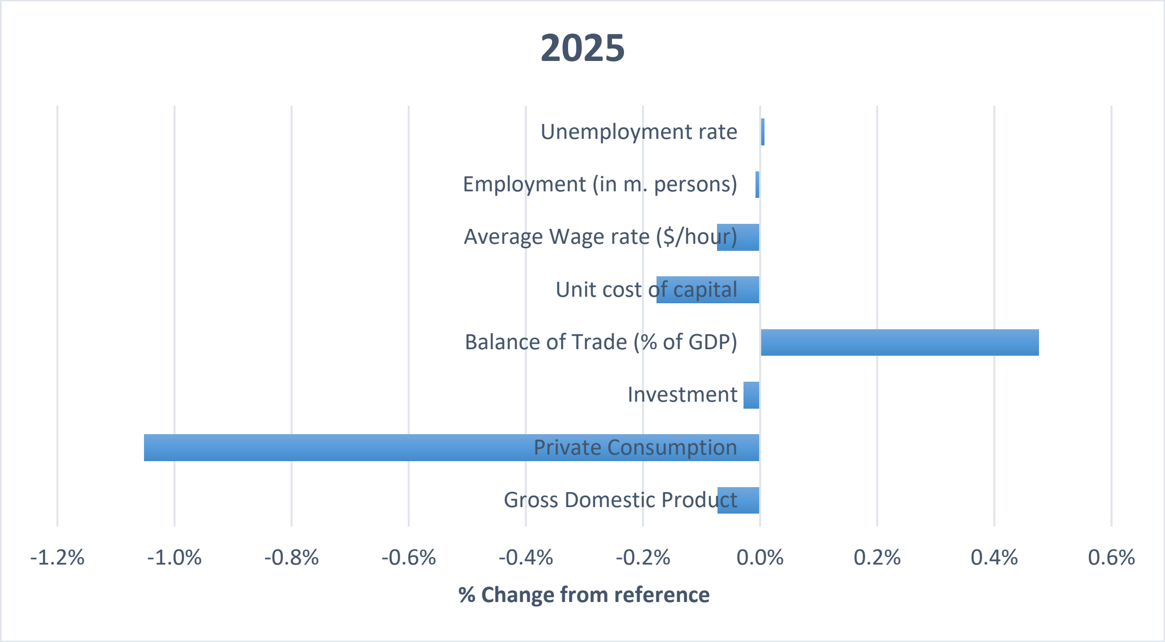
```
* Increase in Direct Taxes for Households
txdirtaxh("SVN",rtime) $(rtime.val > 2020) = txdirtaxh("SVN",rtime) * 1.1;
```

The channels through which the economy is affected are the following:

- ✓ Decrease the household disposable income
- ✓ Lower disposable income decreases private consumption
- ✓ Lower demand for products decreases the demand for all factors of production (i.e., labour and capital)
- ✓ Lower demand for capital and labour decreases their unit costs

Figure 34 shows the results on the key macroeconomic aggregates in 2025.

Figure 34: Key macroeconomic aggregates – BASE-DT



Source: GEM-E3-SI

BASE-SS

In this scenario an increase in the social security contribution of employees by 10% is assumed. The corresponding model parameter for the social security contribution of employees is the txfss_sk. The GAMS code required to be added in the scenario template to increase the social security contribution of employees by 10% for the period 2025 – 2050 is:

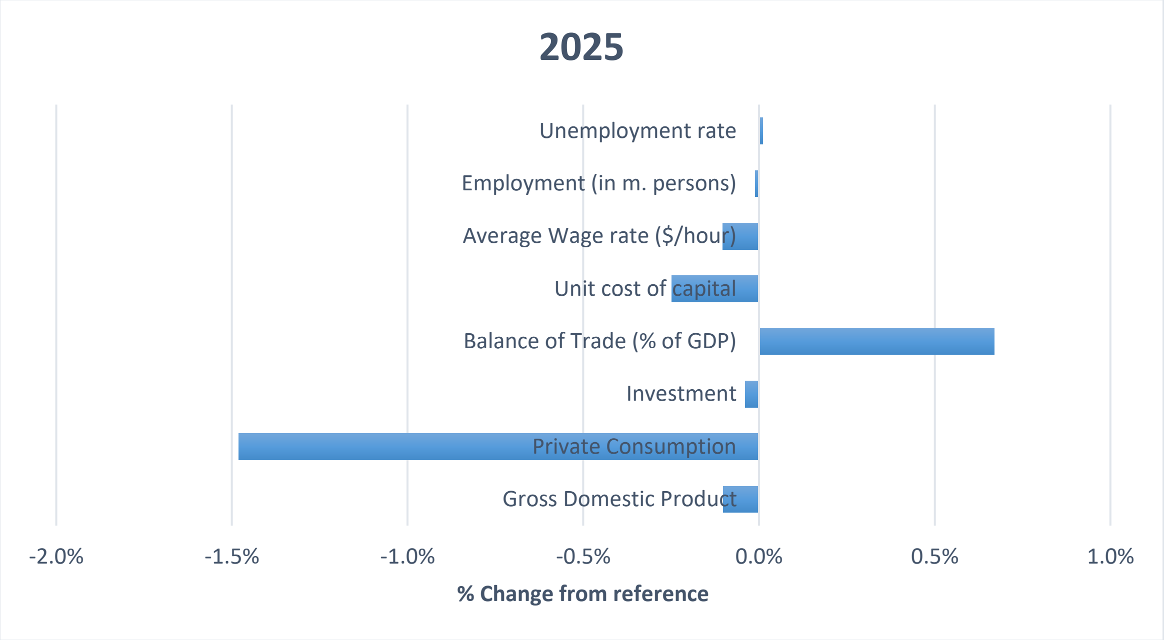
```
* Increase in household social security contribution
txhss_sk(sk_type,"SVN",rtime)$((rtime.val > 2020) and  (txhss_sk(sk_type,"SVN",rtime) > 0))
                              = txhss_sk(sk_type,"SVN",rtime) * 1.1;
```

The channels through which the economy is affected are the following:

- ✓ Decrease the household disposable income
- ✓ Lower disposable income decreases private consumption
- ✓ Lower demand for products decreases the demand for all factors of production (i.e., labour and capital)
- ✓ Lower demand for capital and labour decreases their unit costs

Figure 35 shows the results on the key macroeconomic aggregates in 2025.

Figure 35: Key macroeconomic aggregates – BASE-SS



Source: GEM-E3-SI

Policy scenarios

In this section we quantify and analyze the results of practical policy examples by using the GEM-E3-SI model. A step-by-step approach is used to help the user to understand all the steps required to design, run and analyze the results of a scenario. The simulation of the scenarios will be based on the soft-link approach with the power model hence the respective baseline under this option should be created. The policy scenarios simulated are:

1. Exogenous carbon tax to GHG emission
2. Endogenous GHG target
3. Electrification of transport
4. Energy Efficiency
5. Nuclear plan

Baseline_LINK

The baseline that follows the soft-link approach with the power model requires to set the value of the switch power_link equal to 1. We have used the scenario template: 00_Scenario_name and renamed all the files to Baseline_LINK (i.e., Baseline_LINK.gms, Baseline_LINK.xlsx).

The following steps are followed to run the scenario: Baseline_LINK:

- Modify the code in the Baseline_LINK.gms by setting: $setglobal power_link "1";
- Run the scenario through the GEM-E3-SI interface
- Check the convergence criteria (parameter Elec_convergence in the *Baseline_LINK_Scenario.gdx* stored at …\GEMMOD\RUN_GDX)
- Repeat steps 2 – 3, 10 times, until a convergence criteria is met.

Table 11 shows the results of the parameter Elec_convergence that compares the change in the electricity demand included as input in the power model in two subsequence runs. In the case of a 11th iteration, the new electricity demand that will be used as input in the power model will differ at the year 2050 by 0.01% as compared with the electricity demand used as input in the iteration 10.

Table 11: Convergence in the Baseline_LINK scenario

Iterations	2025	2030	2035	2040	2045	2050
1	0.0569	0.0410	0.0378	0.0393	0.0489	0.0648
2	0.0251	0.0155	0.0159	0.0173	0.0223	0.0305
3	0.0113	0.0060	0.0068	0.0078	0.0103	0.0146
4	0.0051	0.0023	0.0029	0.0035	0.0048	0.0070
5	0.0023	0.0009	0.0012	0.0016	0.0023	0.0034
6	0.0011	0.0004	0.0005	0.0007	0.0011	0.0017
7	0.0005	0.0001	0.0002	0.0003	0.0005	0.0008
8	0.0002	0.0001	0.0001	0.0001	0.0002	0.0004
9	0.0001	0.0000	0.0000	0.0001	0.0001	0.0002
10	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001

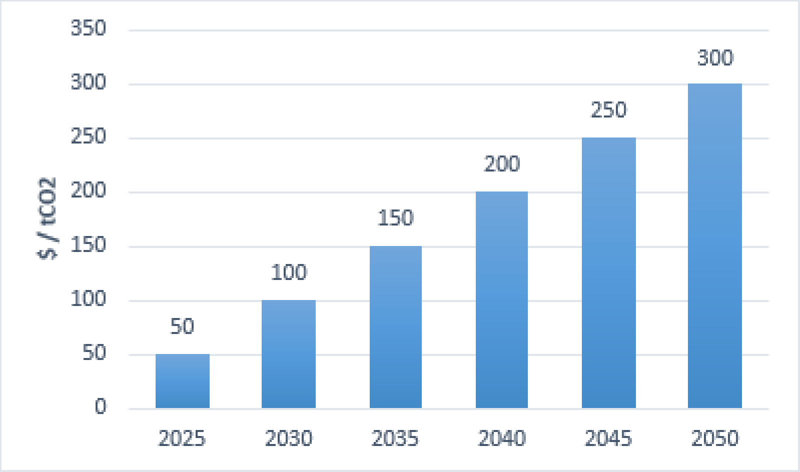
Source: GEM-E3-SI

The baseline projection in the Baseline_LINK scenario will be used as a reference scenario for the comparison of the policy scenarios simulated by using the same option, the soft-link approach with the power model.

Exogenous carbon tax to GHG emission

In the scenario, CTAX_LINK, an economy wide exogenous carbon tax is applied in Slovenian economy. Figure 36 presents the carbon tax applied in all sectors and household for all GHG emissions at the period 2025 – 2050.

Figure 36: Exogenous carbon tax – CTAX_LINK



Source: GEM-E3-SI

The following steps are followed to run the scenario: CTAX_LINK:

- Modify the code in the CTAX_LINK.gms by setting: $setglobal power_link "1";
- Modify the excel file CTAX_LINK.xlsx to represent the policy scenario assumptions
- Run the scenario through the GEM-E3-SI interface
- Check the convergence criteria (parameter Elec_convergence in the *CTAX_LINK_Scenario.gdx* stored at …\GEMMOD\RUN_GDX)
- Repeat steps 2 – 3, 10 times, until a convergence criteria is met.

Table 12 shows the results of the parameter Elec_convergence that compares the change in the electricity demand included as input in the power model in two subsequence runs.

Table 12: Convergence in the CTAX_LINK scenario

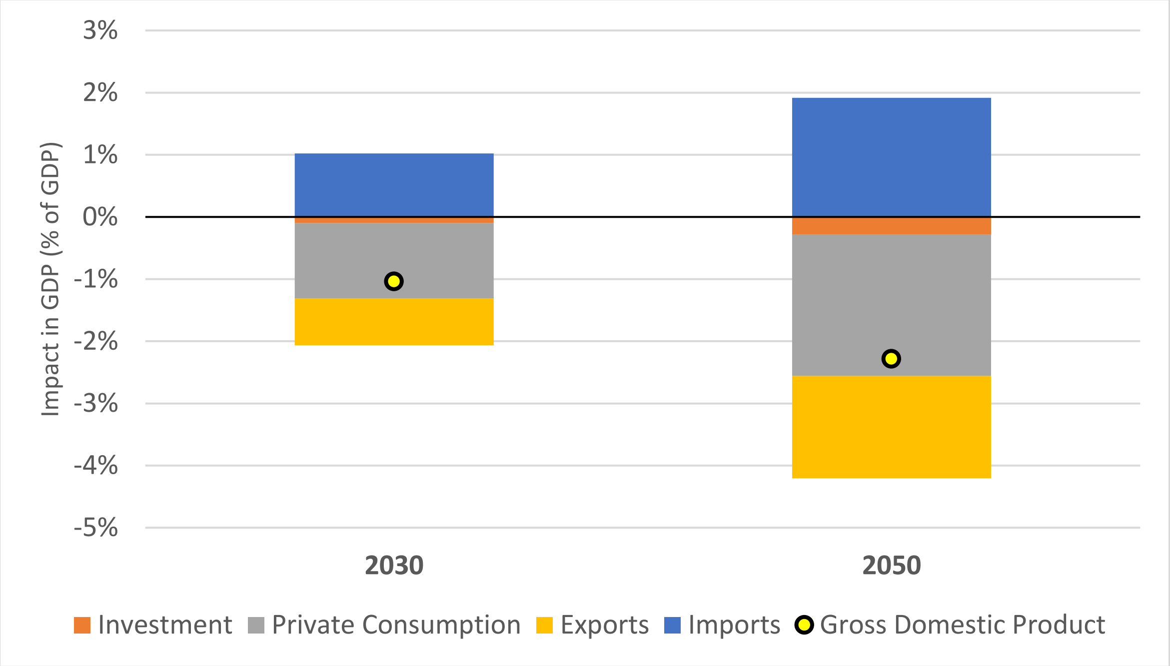
Iterations	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
1	-0.0304	-0.0692	-0.0638	-0.0479	-0.0176	0.0265
2	-0.0111	-0.0080	0.0347	0.1243	0.1632	0.1694
3	-0.0040	-0.0038	0.0164	0.0536	0.0701	0.0757
…	…	…	…	…	…	…
10	0.0000	0.0000	0.0001	0.0002	0.0003	0.0005

Source: GEM-E3-SI

The carbon tax applied in CO2 energy related emissions and in process related GHG emissions increases the unit cost of production in sectors with high fossil fuel share or/and high GHG intensity. The impact in relative prices among sectors directs the demand to sectors with relative lower emission intensity. Export oriented sectors with high emission intensity have severe competitive losses.

Figure 37 presents the impact on GDP decomposed by the key macroeconomic aggregates as compared to the Baseline_LINK scenario. The overall impact in GDP is negative, 1% in 2030 and 2.3% in 2050 affected mainly by the lower private consumption and exports. Lower private consumption implies lower imports with a positive impact on GDP.

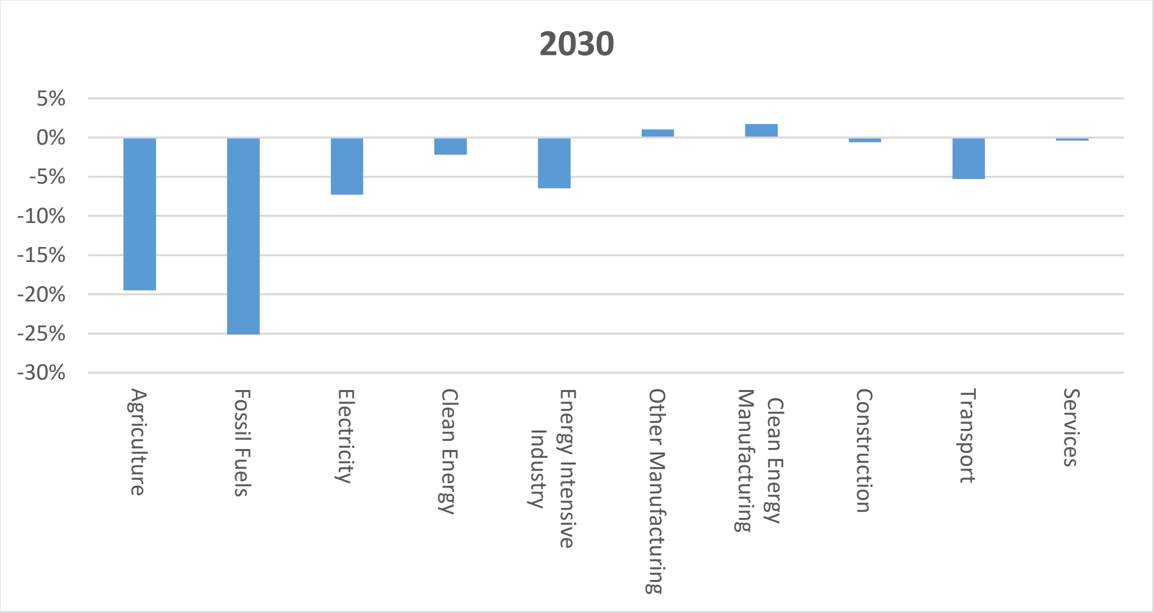
Figure 37: Key macroeconomic aggregates – CTAX_LINK



Source: GEM-E3-SI

At the sectoral level, in 2030 (see Figure 38), sectors are mainly affected by the overall GDP impact. Agriculture and fossil fuels faces the highest negative impact in their production and transport and energy intensive industries follows. The power sector, having 20.4% in fossil fuel based power generation technologies, sees an increase in the unit cost of production with a negative impact in the electricity production. On the positive side, the clean energy and other manufacturing are the sector with slight positive impact in sectoral production.

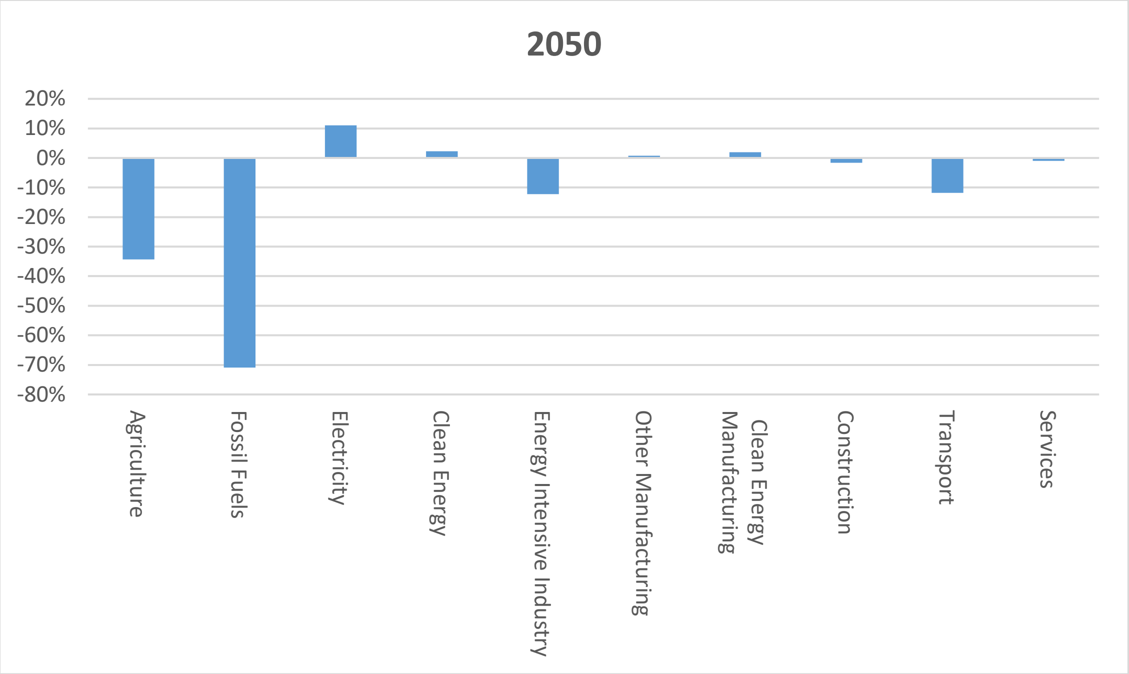
Figure 38: Sectoral production in 2030 – CTAX_LINK



Source: GEM-E3-SI

In 2050 (see Figure 39), the fossil fuel based power generation technologies have a zero share in the electricity generation resulting an increase in the electrification of the economy.

Figure 39: Sectoral production in 2050 – CTAX_LINK

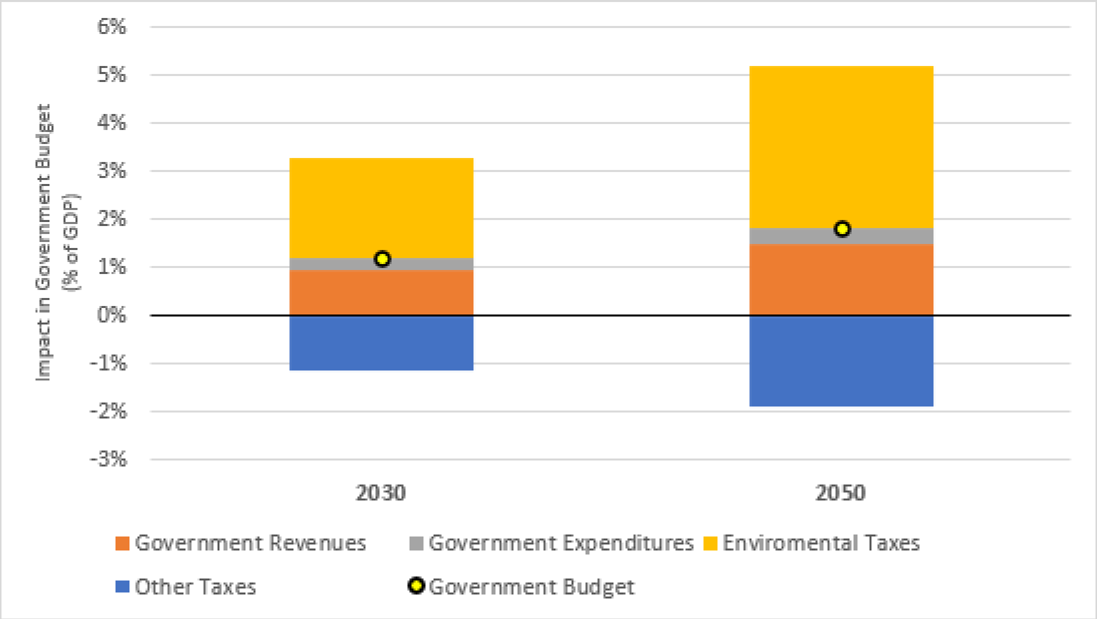


Source: GEM-E3-SI

Fossil fuels production is reduced dramatically. Agriculture have a severe impact on the production due to carbon tax in the process related emissions. Energy intensive industries and transport sectors are mainly affected by the higher energy cost due to the carbon tax in CO_2 energy related emissions.

GHG emissions are reduced by 18.4% in 2030 and by 38.5% in 2050 as compared to the Baseline_LINK scenario. The net impact in Government budget by the additional revenues of the environmental taxes and lower revenues as a result of the lower income generation in the economy is presented in Figure 40.

Figure 40: Impact on Government Budget – CTAX_LINK



Source: GEM-E3-SI

It should be noted that the additional government revenues are not recycled back to the economy but they are used to improve the Government's budget, hence increasing Government savings. Under the free budget option, a reduction in the world interest rate is activated to ensure the macroeconomic closure[20] of the GEM-E3-SI model. The lower interest rate increases the private consumption and reduces the household savings of all countries.

An exogenous carbon tax scenario which recycle back to the Slovenian economy the environmental revenues has also simulated, the CTAX_REC_LINK. In this scenario, a mix of the available recycling options is selected. It is assumed that the 25% of the additional government revenues will be directed to reduce the indirect taxes, 25% to increase the production subsidies, 25% as a lump sum transfer to households and 25% to reduce the social security contribution.

This scenario requires the same steps with the CTAX_LINK by adding only the appropriate values in the share parameter recscheme at the respective scenario template (sheet: RECYCLING). Table 13 shows the results of the parameter Elec_convergence that compares the change in the electricity demand included as input in the power model in two subsequence runs.

Table 13: Convergence in the CTAX_REC_LINK scenario

Iterations	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
1	-0.0253	-0.0598	-0.0510	-0.0318	0.0019	0.0491
2	-0.0101	-0.0059	0.0368	0.1243	0.1635	0.1714
3	-0.0036	-0.0028	0.0173	0.0537	0.0703	0.0766
…	…	…	…	…	…	…
10	0.0000	0.0000	0.0001	0.0002	0.0003	0.0005

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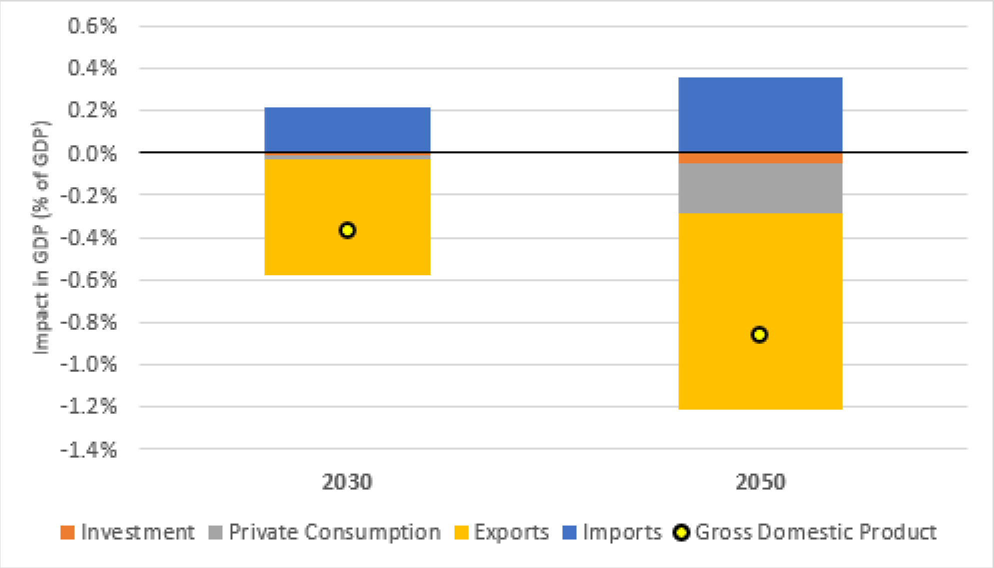
[20] Savings = Investments at the World level.

Source: GEM-E3-SI

Figure 41 presents the impact on GDP decomposed by the key macroeconomic aggregates as compared to the Baseline_LINK scenario. The overall impact in GDP is a much lower negative impact as compared with the CTAX_LINK scenario, 0.36% in 2030 and 0.86% in 2050.

Figure 41: Key macroeconomic aggregates – CTAX_REC_LINK



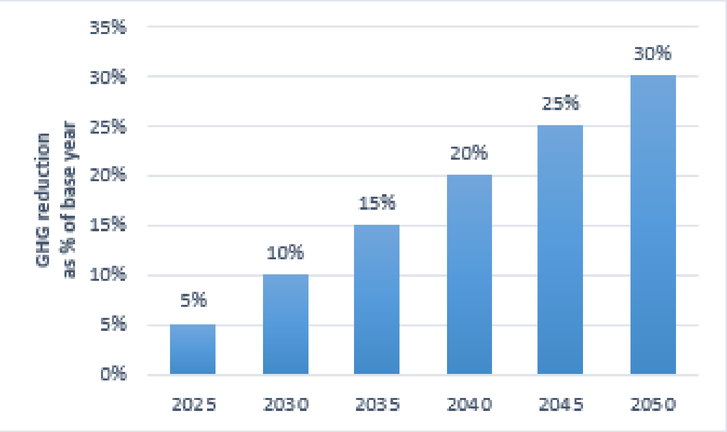
Source: GEM-E3-SI

Endogenous GHG target

In the CTAX_LINK scenario it is found that the carbon tax applied in the process related emissions has severe impact in the agriculture production. Based on this outcome, in the scenario ECTAX_LINK an economy wide exogenous carbon tax is applied in Slovenian economy in all sectors excluding the agriculture sector. Instead an endogenous GHG target is applied only for the agriculture sector.

For the ECTAX_LINK scenario simulation we need to exclude the agriculture sector from the carbon club “01” that the exogenous carbon price is applied and we set an endogenous GHG target for the agriculture sector in a new club (i.e., “02”) as presented in the Figure 42.

Figure 42: Endogenous GHG target in agriculture sector



Source: GEM-E3-SI

In the respective excel file: ECTAX_LINK.xlsx we define the necessary assumptions for this scenario:

- Exclude the agriculture sector from the carbon club: “01”
- Include a new carbon club, “02”, that contains only the agricultural sector, all the GHG emissions and Slovenia, at the period 2025 – 2050
- Add the endogenous targets as compared to the base year to the sheet: TARGET_GHG_BYEAR

Table 14 shows the results of the parameter Elec_convergence that compares the change in the electricity demand included as input in the power model in two subsequence runs.

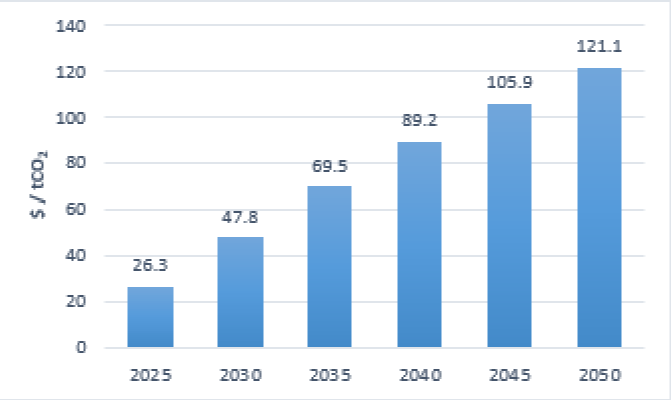
Table 14: Convergence in the ECTAX_LINK scenario

Iterations	2025	2030	2035	2040	2045	2050
1	-0.0317	-0.0708	-0.0655	-0.0495	-0.0193	0.0247
2	0.0093	0.0306	0.0704	0.1539	0.1734	0.1530
3	-0.0027	-0.0014	-0.0019	-0.0102	-0.0092	-0.0031
…	…	…	…	…	…	…
10	0.0000	0.0000	0.0001	0.0002	0.0003	0.0005

Source: GEM-E3-SI

The carbon price computed endogenously by the GEM-E3-SI model to meet the GHG target for the agriculture sector is presented in Figure 43. This corresponds to the value of the P_PCLUB variable, as derived from the GAMS file …\GEMMOD\RUN_GDX\ECTAX_LINK_Scenario.gdx, regarding the club “02” and all the GHG emissions.

Figure 43: Endogenous carbon price for the agriculture sector – ECTAX_LINK



Source: GEM-E3-SI

The results are very similar to the CTAX_LINK but with a much lower impact on the agriculture sector.

Electrification of transport

In this scenario, the key exogenous assumptions regarding the private transport in the TRA_LINK scenario are presented below. It is assumed that the stock of passenger cars follows the trajectory presented in Table 15 at the reference case and in Table 16 at the TRA_LINK scenario.

Table 15: Stock of passenger cars in the reference case

passenger cars (in '000)	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Stock	1000	1100	1200	1300	1400	1500	1600
Electric cars	0	0	0	0	0	0	0
Conventional cars	1000	1100	1200	1300	1400	1500	1600
New stock		80	80	80	80	80	80
Electric cars		0	0	0	0	0	0
Conventional cars		80	80	80	80	80	80
Deregistration		60	60	60	60	60	60
Electric cars		0	0	0	0	0	0
Conventional cars		60	60	60	60	60	60

Table 16: Stock of passenger cars – TRA_LINK

passenger cars (in '000)	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Stock	1000	1100	1200	1300	1400	1500	1600
Electric cars	0	100	300	600	950	1250	1500
Conventional cars	1000	1000	900	700	450	250	100
New stock		80	80	80	80	80	80
Electric cars		20	40	60	80	80	80
Conventional cars		60	40	20	0	0	0
Deregistration		60	60	60	60	60	60
Electric cars		0	0	0	10	20	30
Conventional cars		60	60	60	50	40	30

The assumptions regarding the price trajectory for the passenger cars is presented in Table 17, on activity in Table 18 and on energy use in Table 19. It indicates that the electric cars are 4 times more efficient than the conventional cars.

Table 17: Price of passenger cars – TRA_LINK

Price of Car (in $)	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Electric	30000	30000	30000	30000	30000	30000	30000
Conventional	20000	20000	20000	20000	20000	20000	20000

Table 18: Activity – TRA_LINK

Activity (in Gvkm)	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total	15.0	16.5	18.0	19.5	21.0	22.5	24.0
Electric cars	0.0	1.5	4.5	9.0	14.3	18.8	22.5
Conventional cars	15.0	15.0	13.5	10.5	6.8	3.8	1.5

Table 19: Energy use in operation of vehicles – TRA_LINK

Energy use (ktoe)	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total	600	615	585	510	413	338	285
Electricity	0	15	45	90	143	188	225
Oil	600	600	540	420	270	150	60

The following steps required for the implementation of the TRA_LINK scenario:

- Change the purchases of vehicles
- Change the energy mix of the operation of vehicles
- Change the energy efficiency related to the use of the electric cars

5.1.1.1 Change in purchases of vehicles

Table 20 presents the additional expenditures in purchases of passenger cars based on the key scenario assumptions. The household consumption in the GEM-E3-SI model is based on the LES utility function. The consumption by purpose that represent the purchases of vehicles is the “fn = 08”. The parameters that allocates the total household consumption expenditures to consumption by purpose are the chcfv (minimum consumption by purpose) and the bhcfv (share parameter based on income elasticity).

The consumption by purpose is linked to consumption by product via a consumption matrix with constant technical coefficients, the thcfv parameter. In the Baseline_LINK scenario this parameter has a high share in the manufacturing of conventional vehicles (IND11: Transport equipment (excluding EV)) and a small share in the manufacturing of electric vehicles (IND15: EV Transport Equipment). Table 21 presents the technical coefficients in the purchases of vehicles consumption by purpose.

Table 20: Additional household expenditures in purchases of passenger cars – TRA_LINK

in b.$	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total		0.20	0.40	0.60	0.80	0.80	0.80
Electric cars		0.60	1.20	1.80	2.40	2.40	2.40
Conventional cars		-0.40	-0.80	-1.20	-1.60	-1.60	-1.60

Table 21: Technical coefficients in the consumption matrix – purchases of vehicles

Sector	**thcfv**
Transport equipment (excluding EV)	77.2%
Consumer Goods Industries	5.1%
Market Services	16.6%
Non Market Services	0.1%
`EV Transport Equipment	1.0%

The GAMS code used to apply the new shares of household consumption expenditures in purchasing of vehicles is presented below:

```
thcfv_fn08(pr,"SVN",rtime)       $(rtime.val > 2020)
                                 = thcfv(pr,"08","SVN",rtime);

thcfv_fn08(pr_traeq,"SVN",rtime)$(rtime.val > 2020)
                                 = HH_share(pr_traeq,rtime)  *
                                 ( thcfv(pr_traeq,"08","SVN",rtime)
                                 + thcfv(pr_evh,"08","SVN",rtime));

thcfv_fn08(pr_evh,"SVN",rtime)   $(rtime.val > 2020)
                                 = HH_share(pr_evh,rtime)  *
                                 ( thcfv(pr_traeq,"08","SVN",rtime)
                                 + thcfv(pr_evh,"08","SVN",rtime));

* Update of the technical coefficients
thcfv(pr,"08","SVN",rtime)       $(rtime.val > 2020)
                                 = thcfv_fn08(pr,"SVN",rtime);
```

where HH_share the shares presented in Table 22.

Table 22: Share of household expenditures in purchases of passenger cars – TRA_LINK

	2025	**2030**	**2035**	**2040**	**2045**	**2050**
Electric cars	33.3%	60.0%	81.8%	100.0%	100.0%	100.0%
Conventional cars	66.7%	40.0%	18.2%	0.0%	0.0%	0.0%

5.1.1.2 Change in the energy mix of the operation of vehicles

The scenario template should be used to apply the electrification share in the operation of vehicles. In sheet: ELECTRIFICATION of the excel file: TRA_LINK.xlsx we load the electricity shares as calculated by the Table 19 and presented in Table 23. We enable the electricity shares In the TRA_LINK.gms by using the switch: shr_ELE_HH.

Table 23: Energy mix of the operation of vehicles – TRA_LINK

Shares in Energy mix	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Electricity	0.0%	2.4%	7.7%	17.6%	34.5%	55.6%	78.9%
Oil	100.0%	97.6%	92.3%	82.4%	65.5%	44.4%	21.1%

5.1.1.3 Change in the energy mix of the operation of vehicles

The change in the energy mix direct the consumption from oil to electricity without getting into account the technological improvement that the electric vehicles are more efficient than the conventional vehicles. The parameter tgqtch[21] should be changed to represent the technological improvement. A value of ln(4) = 1.3286 represents an efficiency in a way that the electricity required for 1 unit of the operation of vehicles (i.e., passenger km) will be 4 times less than the quantity required from other products (i.e. gasoline).

The following GAMS code is added in the TRA_LINK.gms:

```
* Change in the energy efficiency for electricity in operation of vehicles
tgqtch(pr_ele,"09","SVN",rtime) $(rtime.val > 2020)
                                = 1.3286;
```

5.1.1.4 Results

By following all the steps described in the previous subsections the scenario TRA_LINK have simulated. Table 24 shows the results of the parameter Elec_convergence that compares the change in the electricity demand included as input into the power model in two subsequent runs.

Table 24: Convergence in the TRA_LINK scenario

Iterations	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
1	-0.0294	-0.0641	-0.0489	-0.0133	0.0486	0.1413
2	-0.0108	-0.0055	0.0417	0.1376	0.1873	0.2121
3	-0.0039	-0.0027	0.0196	0.0593	0.0801	0.0933
…	…	…	…	…	…	…
11	0.0000	0.0000	0.0001	0.0001	0.0002	0.0003

Source: GEM-E3-SI

The results in this subsection are compared with the CTAX_LINK scenario. In 2030, there is a negative impact in GDP, -0.2% as compared with the CTAX_LINK scenario (Figure 44). The higher cost of purchasing the electric passenger cars implies a redirection of the household consumption. Consumption of purposes with high local content (i.e., recreational, food etc.) are replaced by additional expenditures in purchases

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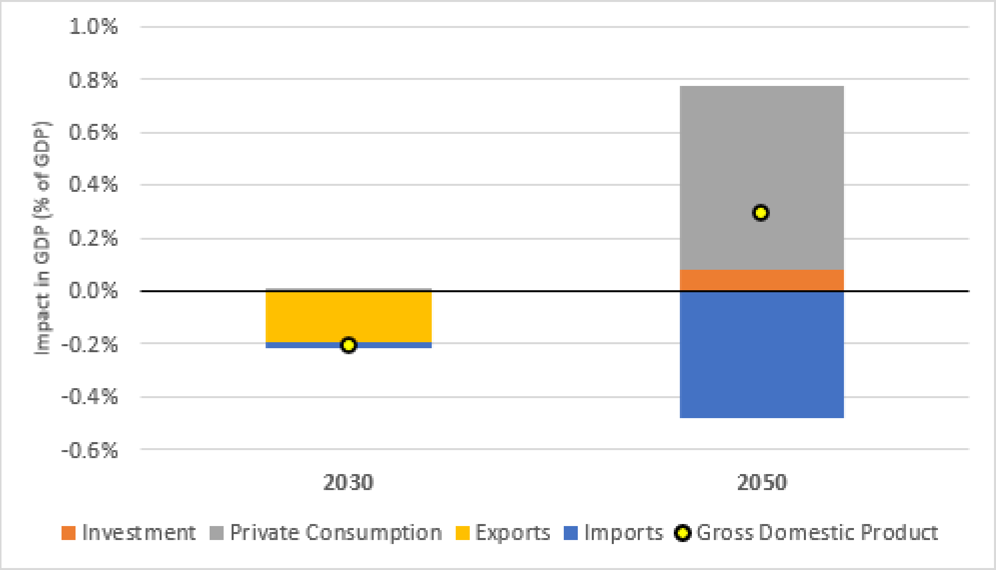
[21] Please note that the tgqtch parameter follows an exponential functional form in the household demand function.

of vehicles. This replacement allocates the demand in the manufacturing of electric vehicles and batteries, sectors with high import share.

Figure 44: Key macroeconomic aggregates – TRA_LINK

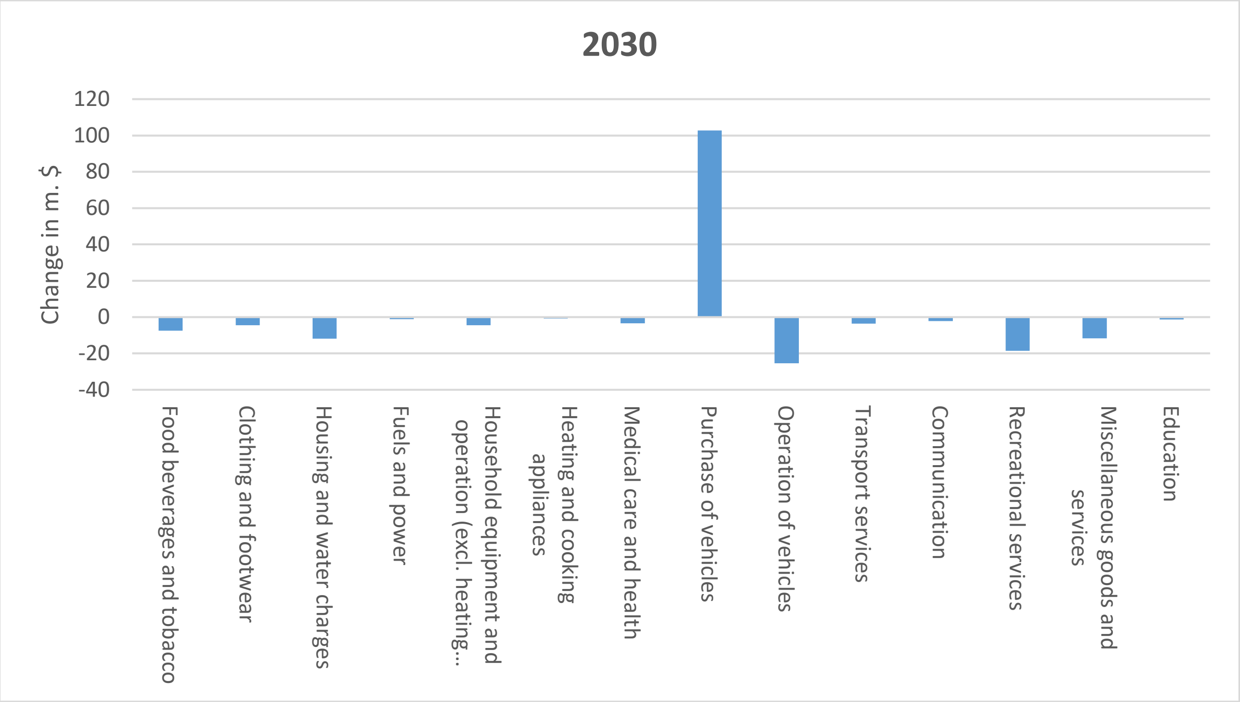


Source: GEM-E3-SI

In the long term, 2050, the stock of conventional passenger cars are replaced by the more efficient electric cars. This replacement implies cumulative efficiency gains in the longer term which reduces the operation costs of vehicles. The lower energy expenditures allow households to increase the private consumption with positive impact in GDP by 0.3% in 2050.

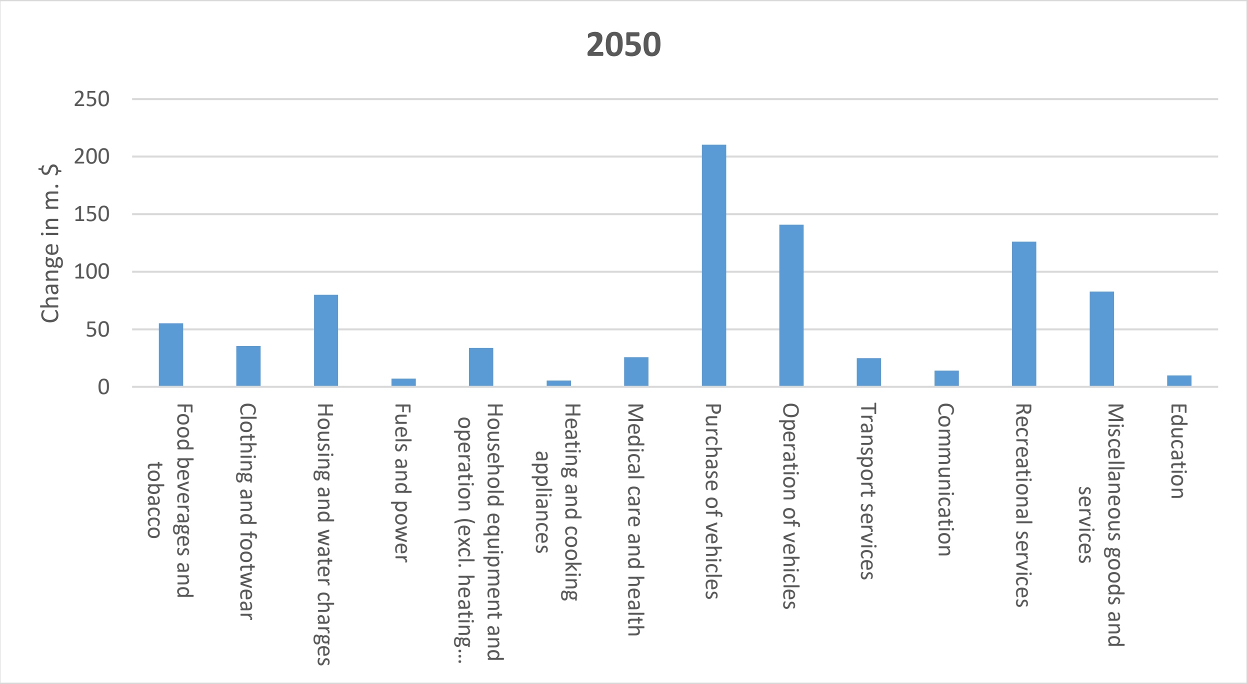
Figure 45 and Figure 46 present the change In household consumption (in m. $) as compared with the CTAX_LINK scenario. In 2030, the additional household consumption expenditures in purchasing of vehicles crowding out consumption for other purposes. In 2050, the efficiency gains allow households to increase their consumption for all consumption categories.

Figure 45: Household consumption by purpose, 2030 – TRA_LINK scenario



Source: GEM-E3-SI

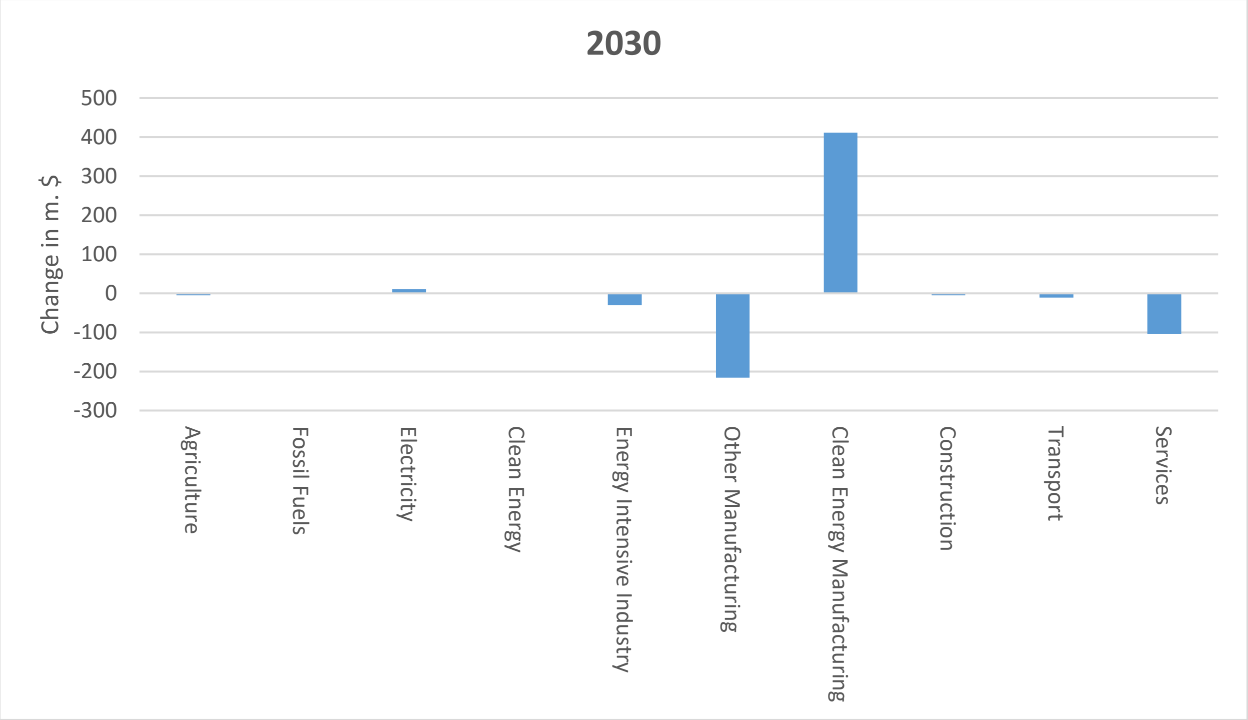
Figure 46: Household consumption by purpose, 2050 – TRA_LINK scenario



Source: GEM-E3-SI

Figure 47 and Figure 48 present the results at the sectoral level. The clean energy manufacturing (i.e., EV transport equipment and batteries) sees benefits. The domestic production of electric vehicles increases demand for batteries which are mostly imported. The other manufacturing sectors (including the conventional transport equipment) face a lower demand and thus lower production as compared with the CTAX_LINK scenario.

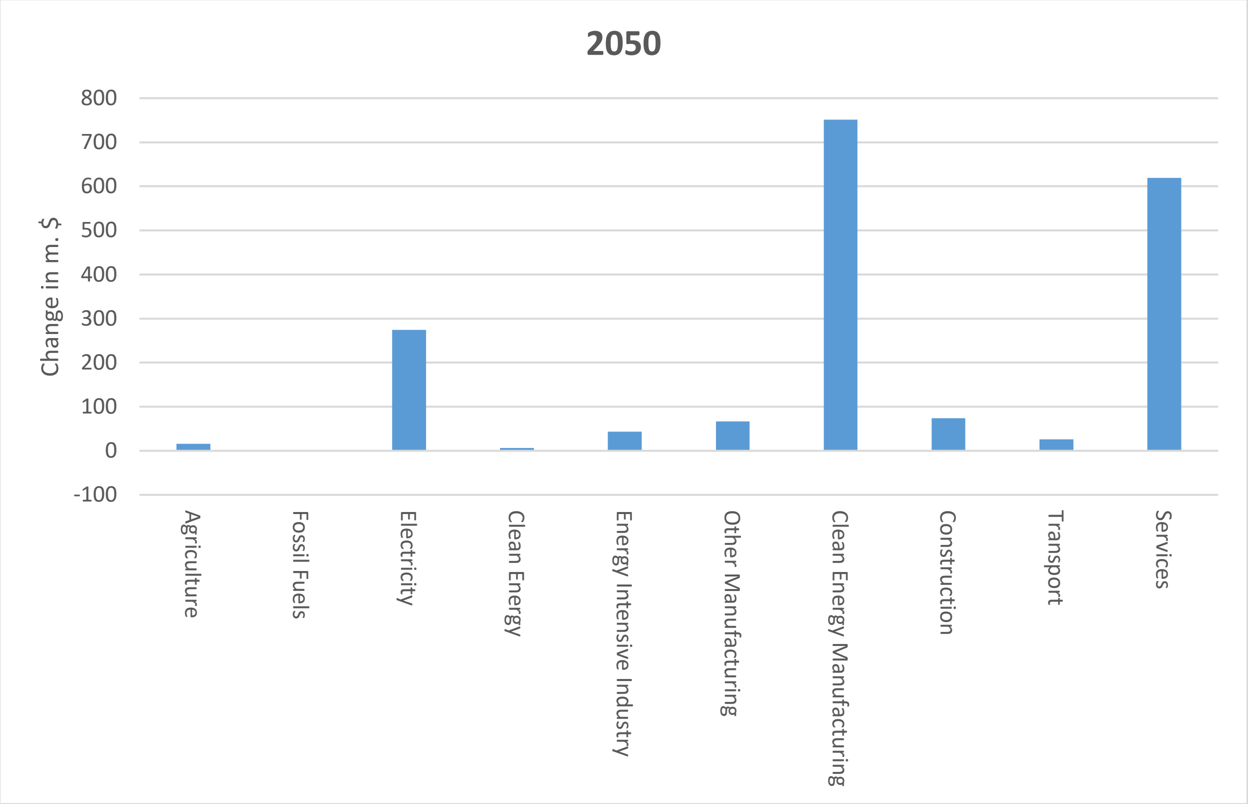
Figure 47: Sectoral production, 2030 – TRA_LINK



Source: GEM-E3-SI

In 2050, clean energy manufacturing continues to have positive impact in its' production. The electrification in private cars increase electricity demand and thus production. The efficiency gains from the use of electric vehicles allow to redirect consumption from gasoline, a highly imported good in Slovenia economy, to electricity, which is produced locally, and to other products including services with much higher local content as compared to the oil products.

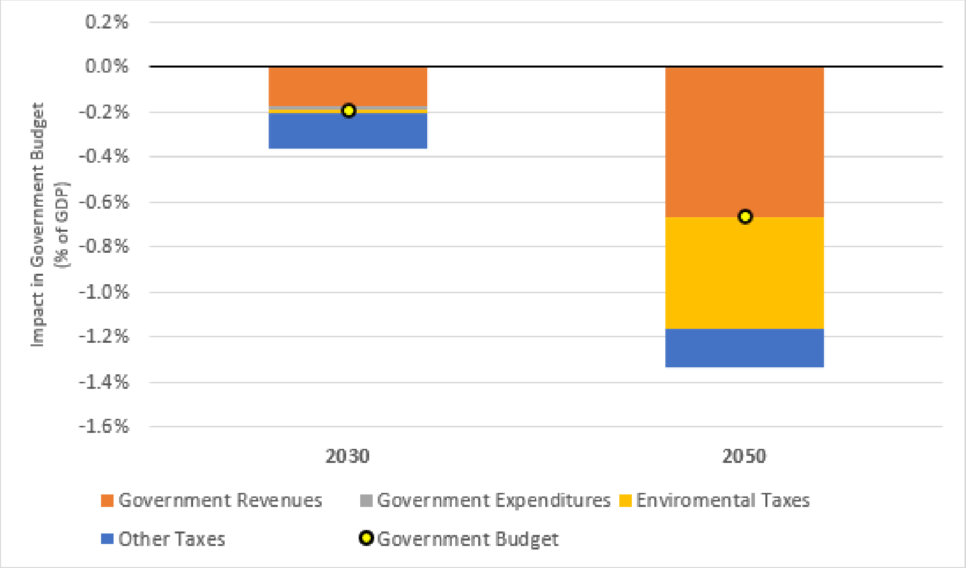
Figure 48: Sectoral production, 2050 – TRA_LINK



Source: GEM-E3-SI

On the fiscal level, the electrification in private transport has a negative impact in the government revenues as the lower demand for oil products lead to lower revenues from both the environmental taxes and the indirect taxes in oil products as compared with the CTAX_LINK scenario (Figure 49).

Figure 49: Impact in Government Budget – TRA_LINK



Source: GEM-E3-SI

Energy Efficiency

In this scenario, in addition to the CTAX_LINK scenario, it is assumed that an energy efficiency program on building renovation with an annual budget of 100 m. $ take place in the period 2025 – 2029. The program is financed by 50% from the Government Budget and by 50% from households

The following steps are followed to run the scenario EE_LINK:

- Fill in 2025 the energy efficiency expenditures for renovation in households in the sheet: EE_Targets in the EE_LINK.xlsx
- Enable the switch: h_select_renov to activate the energy efficiency gains through the energy efficiency curve
- Change the parameter sh_finance from 1 to 0.5

Table 25 shows the results of the parameter Elec_convergence that compares the change in the electricity demand included as input in the power model in two subsequence runs.

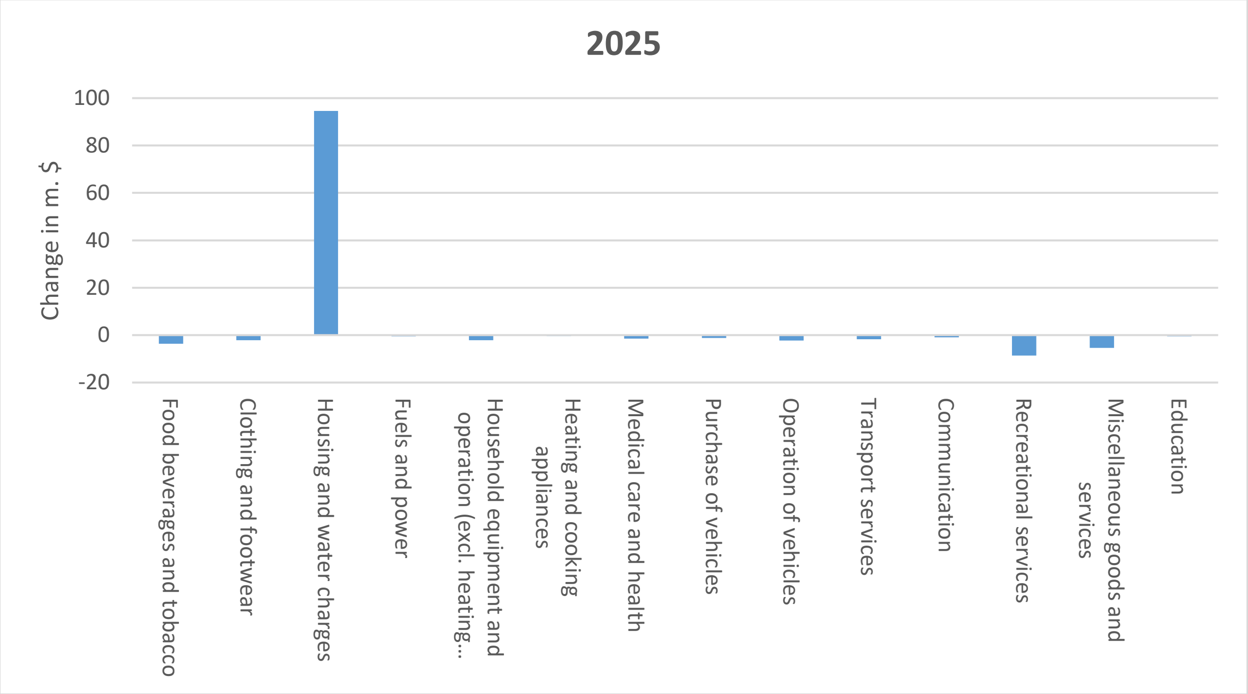
Table 25: Convergence in the EE_LINK scenario

Iterations	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
1	-0.0308	-0.0774	-0.0716	-0.0554	-0.0250	0.0192
2	-0.0113	-0.0121	0.0309	0.1213	0.1605	0.1667
3	-0.0040	-0.0058	0.0146	0.0523	0.0689	0.0745
…	…	…	…	…	…	…
10	0.0000	0.0000	0.0001	0.0002	0.0003	0.0005

Source: GEM-E3-SI

In 2025, the 50% subsidy for renovation that is directed to households deteriorates the Government Budget but increases the private consumption. The financing of the other part of the 50% required in the renovation program is financed through the redirection of the consumption expenditures (Figure 50).

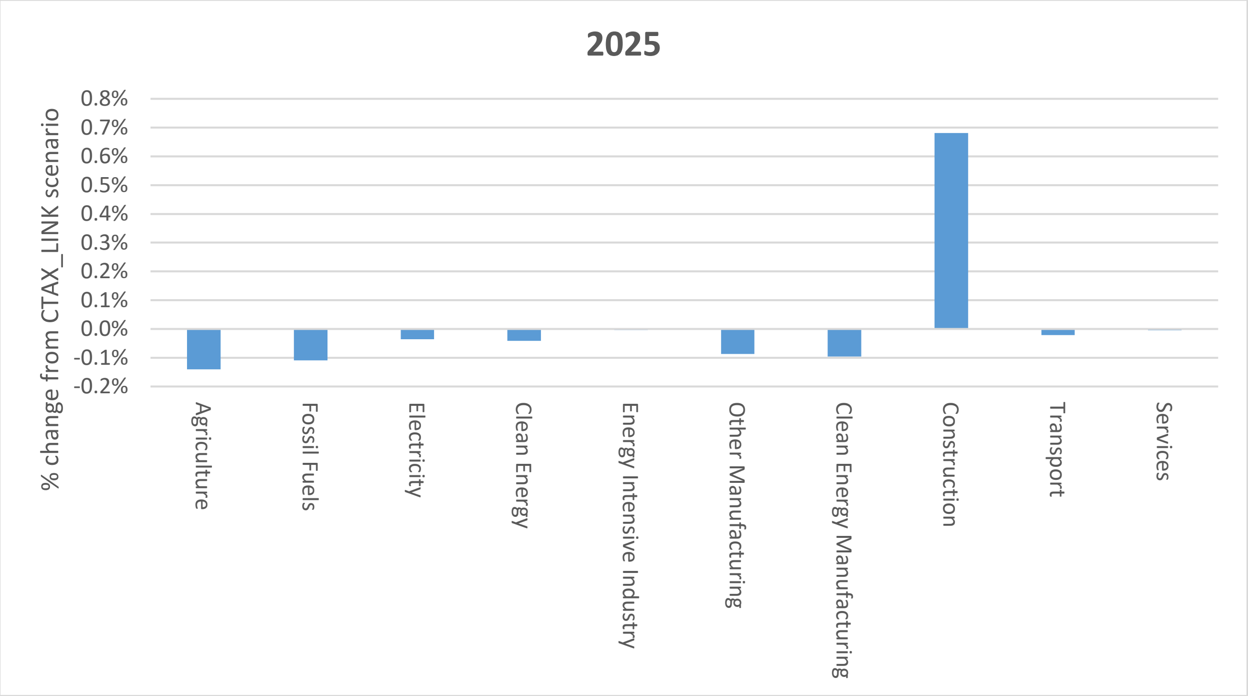
Figure 50: Household consumption expenditures, 2025 – EE_LINK



Source: GEM-E3-SI

The renovation expenditures increases the demand to sectors that producing the renovation activities that are mainly domestically produced (i.e., construction, non-metallic minerals, Figure 51).

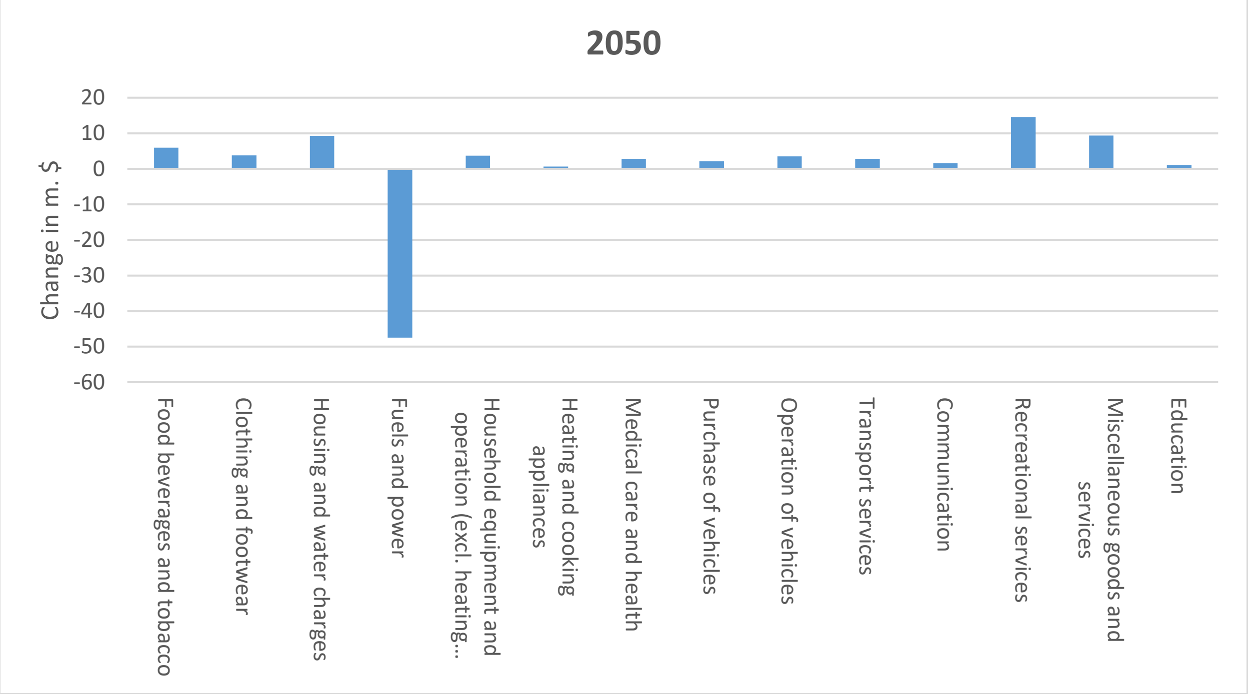
Figure 51: Sectoral production, 2025 – EE_LINK



Source: GEM-E3-SI

In 2050, the energy efficiency gains release expenditures from the imported fossil fuels products to other consumption purposes (Figure 52).

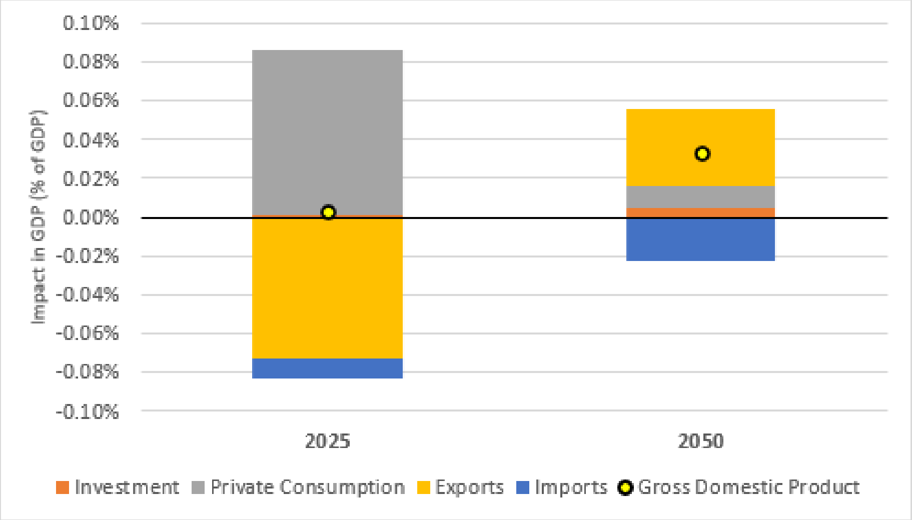
Figure 52: Household consumption expenditures, 2025 – EE_LINK



Source: GEM-E3-SI

The impact in GDP nearly zero 2025 (Figure 53) driven positively by the additional private consumption that subsidized by the government budget and negatively by the increases in the unit cost of capital[22] that deteriorates the trade balance (i.e., increase imports and decreases exports with a negative impact in GDP) .

Figure 53: Key macroeconomic aggregates – EE_LINK



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[22] The increased demand for domestic products for renovation put a pressure in the capital market increasing the unit cost of capital in 2025.

Source: GEM-E3-SI

In 2050, there is a small positive impact in GDP, 0.03% as compared to the CTAX_LINK scenario, due to the energy efficiency gains and the redirection of consumption from the imported fossil fuels consumption to other consumption purposes that increases the domestic demand and production.

Nuclear plan

Based on the CTAX_LINK scenario, an investment in a new nuclear power station of 700 MW is added as exogenous assumption in the NUC_LINK scenario. It is assumed that the nuclear plant will become operational at 2030.

In the respective excel file: NUC_LINK.xlsx we define the necessary assumptions for this scenario:

- Add 700 MW of additional investment for the nuclear plant in 2030 in the sheet: Exogenous_INV

Table 26 shows the results of the parameter Elec_convergence that compares the change in the electricity demand included as input in the power model in two subsequence runs.

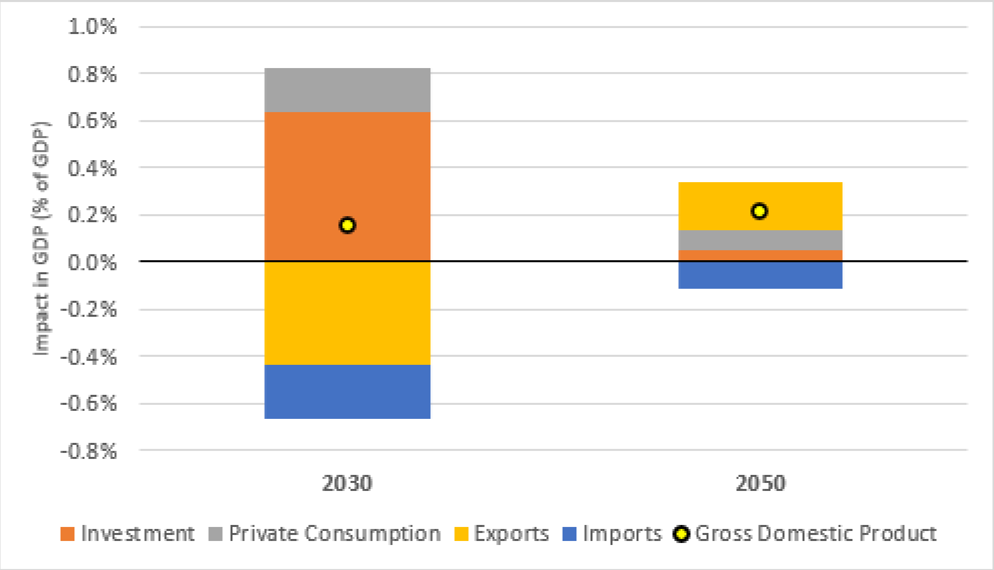
Table 26: Convergence in the NUC_LINK scenario

Iterations	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
1	-0.0317	-0.0708	-0.0655	-0.0495	-0.0193	0.0247
2	0.0093	0.0306	0.0704	0.1539	0.1734	0.1530
3	-0.0027	-0.0014	-0.0019	-0.0102	-0.0092	-0.0031
…	…	…	…	…	…	…
10	0.0000	0.0001	0.0001	0.0001	0.0003	0.0003

Source: GEM-E3-SI

Figure 54 presents the impact on GDP decomposed by the key macroeconomic aggregates as compared to the CTAX_LINK scenario. The overall impact in GDP is positive, 0.16% in 2030 and 0.22% in 2050 affected by different channels.

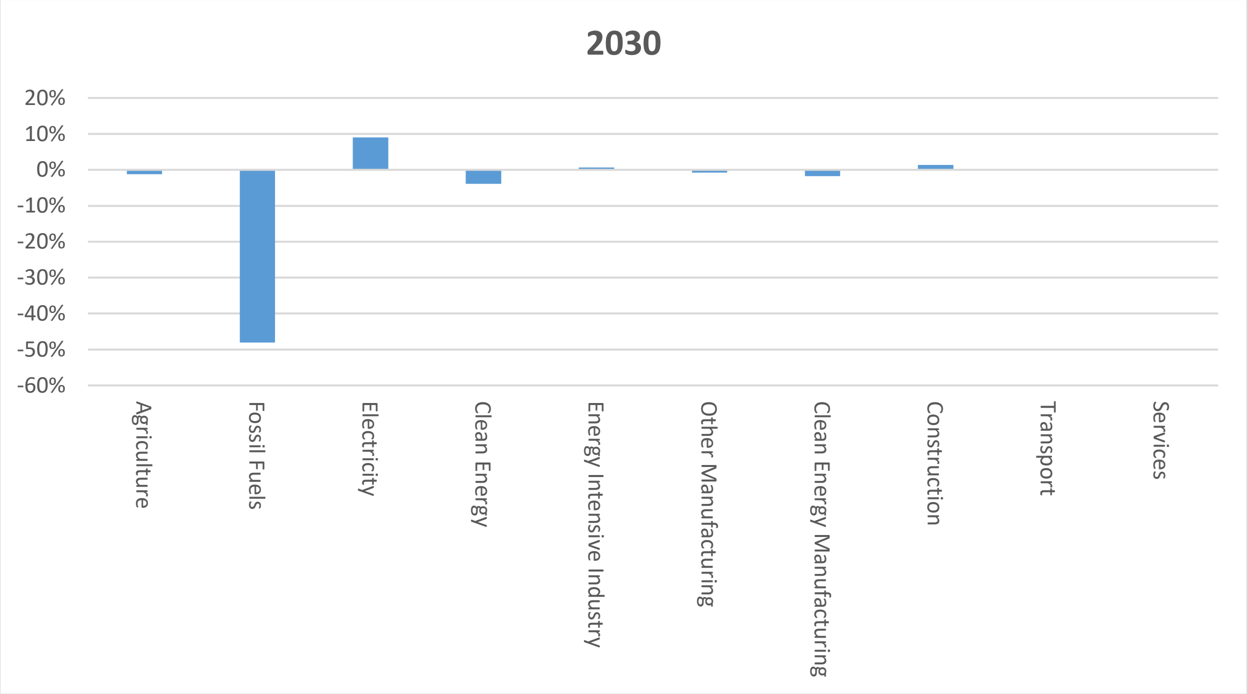
Figure 54: Key macroeconomic aggregates – NUC_LINK



Source: GEM-E3-SI

The additional to reference investments in nuclear plant in 2030 increases GDP and generate income that boosts private consumption. The limited resources in the economy put a pressure in the capital market increasing the unit cost of capital and deteriorating the trade balance (i.e., increases imports and decreases exports with a negative impact in GDP). At the sectoral level, the resources are directed to the production processes required to build the nuclear plant (i.e., construction). The new nuclear plant allows to phase out coal-fired plants with a negative impact in the demand of fossil fuels. The unit cost of electricity is lower as compared with the CTAX_LINK scenario with a positive impact in demand and production (Figure 55). The overall impact in GDP in 2030 is an increase 0.16% as compared with the CTAX_LINK scenario driven by the investments.

Figure 55: Sectoral production, 2030 – NUC_LINK

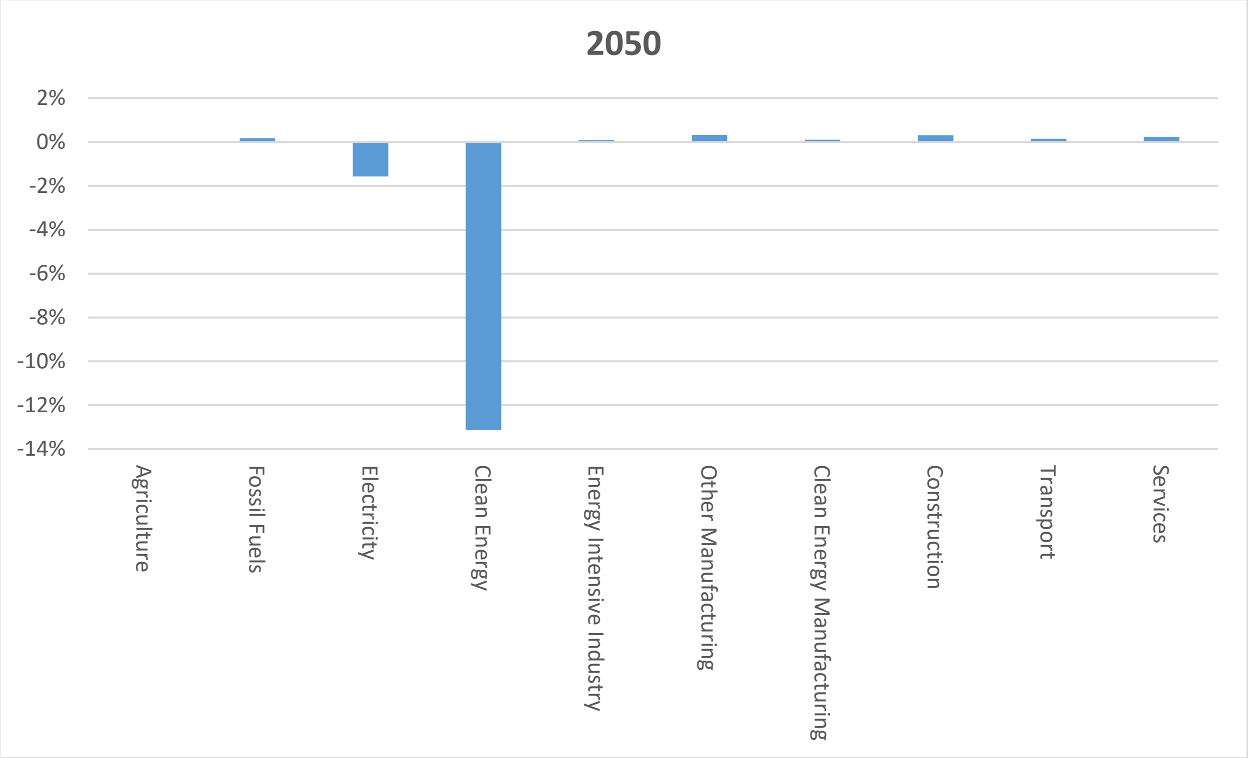


Source: GEM-E3-SI

In the period after 2030, investment plans in RES (PV, Wind and Biomass) selected in the CTAX_LINK scenario are now cancelled due to the additional capacity of the nuclear plant in 2030. As a result, there is a higher penetration of the nuclear energy in power mix as compared with the CTAX_LINK scenario.

The additional capital stock in the period 2035 - 2050 reduces the unit cost of capital with positive impacts in GDP. The decrease in the unit cost of capital imply a decrease in the unit cost of production with competitiveness gains in exports as compared with the CTAX_LINK scenario. The overall impact in GDP in 2050 is an increase 0.22% as compared with the CTAX_LINK scenario driven by the exports. At the sectoral level, the lower penetration of RES in the power sector as compared with the CTAX_LINK scenario implies lower demand for biomass (Figure 56).

Figure 56: Sectoral production, 2050 – NUC_LINK



Source: GEM-E3-SI

6 Suggested model extensions and recommendations to improve and further develop the modelling framework

We consider four key areas where the GEM-E3-SI model could be further developed:

- Accounting for physical Impacts
- Transport
- GHG emissions and abatement options from the Agriculture sector
- Treatment of uncertainty

Physical Impacts

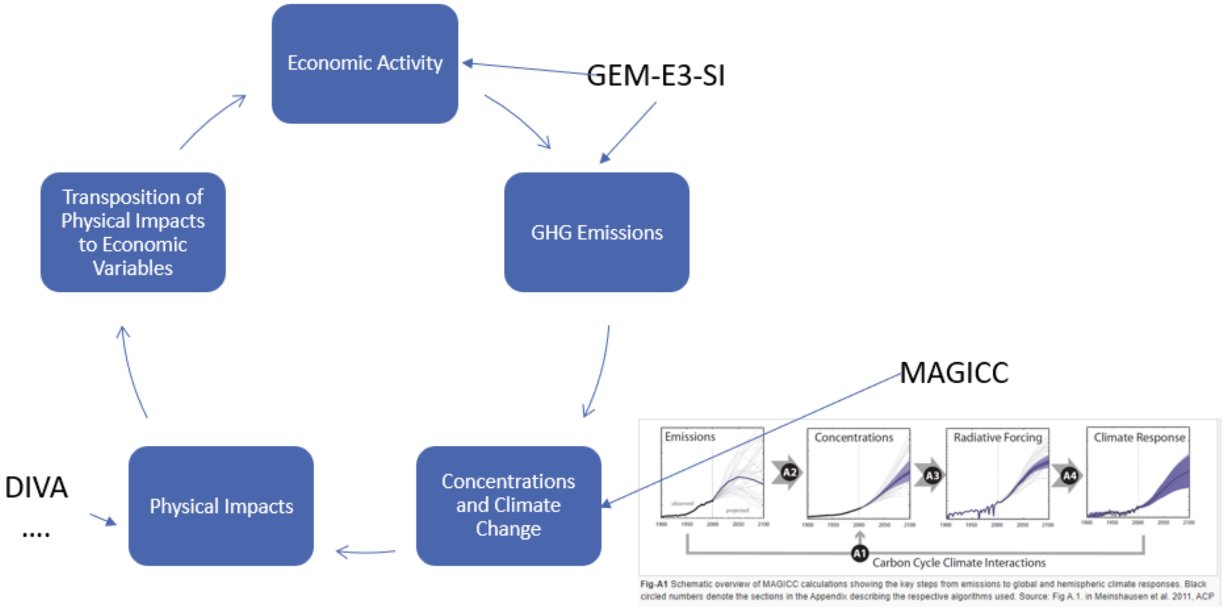
Two types of risk are associated with climate change: i) Transition risks which relate to policy and regulation, technology development and consumer preferences and ii) Physical risks which according to ECB(2021) a p*hysical risk refers to "the financial impact of a changing climate, including more frequent extreme weather events and gradual changes in climate, as well as environmental degradation, such as air, water and land pollution, water stress, biodiversity loss and deforestation. Physical risk is categorized as "acute" when it arises from extreme events, such as droughts, floods and storms, and "chronic" when it arises from progressive shifts, such as increasing temperatures, sea level rise, water stress, biodiversity loss, land use change, habitat destruction and resource scarcity. This can directly result in, for example, damage to property or reduced productivity, or indirectly lead to subsequent events, such as the disruption of supply chains***".**

The GEM-E3-SI model can be extended to establish links between physical damages/changes and economic activities/indicators so as to be able to perform a full economic impact assessment on physical impacts. The coupled model should be able to answer the following questions:

- How damages on infrastructure affect economic performance (through impact on productivity, through repair and demand stimulus effect / financing stress).
- How damages on land and associated changes in crop yields affect agricultural production.
- How the changes in climate and weather conditions that affect tourism arrivals, impact the economy

A suggested modelling suite would require the use of three types of models: i) Economic models (GEM-E3-SI), ii) Climatic Models (e.g. MAGICC) and iii) Physical impact models. The sequence of linking is presented the figure below.

Figure 57: Suite of Models for Physical Impact Assessment



Transport

Transport accounted for the largest share of Slovenia's GHG emissions in 2019, with 32.3 % of the total. Emissions from transport rose by 25.6 % in the 2005- 2019 period, representing an increase of 10.8 percentage points in the share of total emissions. Abatement options such as electrification requires discrete representation of technology option CAPEX and OPEX. To this end it is important that the representation of transport both from accounting and modelling perspective have to be extended. Possible extensions are provided in the figure below.

Figure 58: Suggested consumption decision tree for households

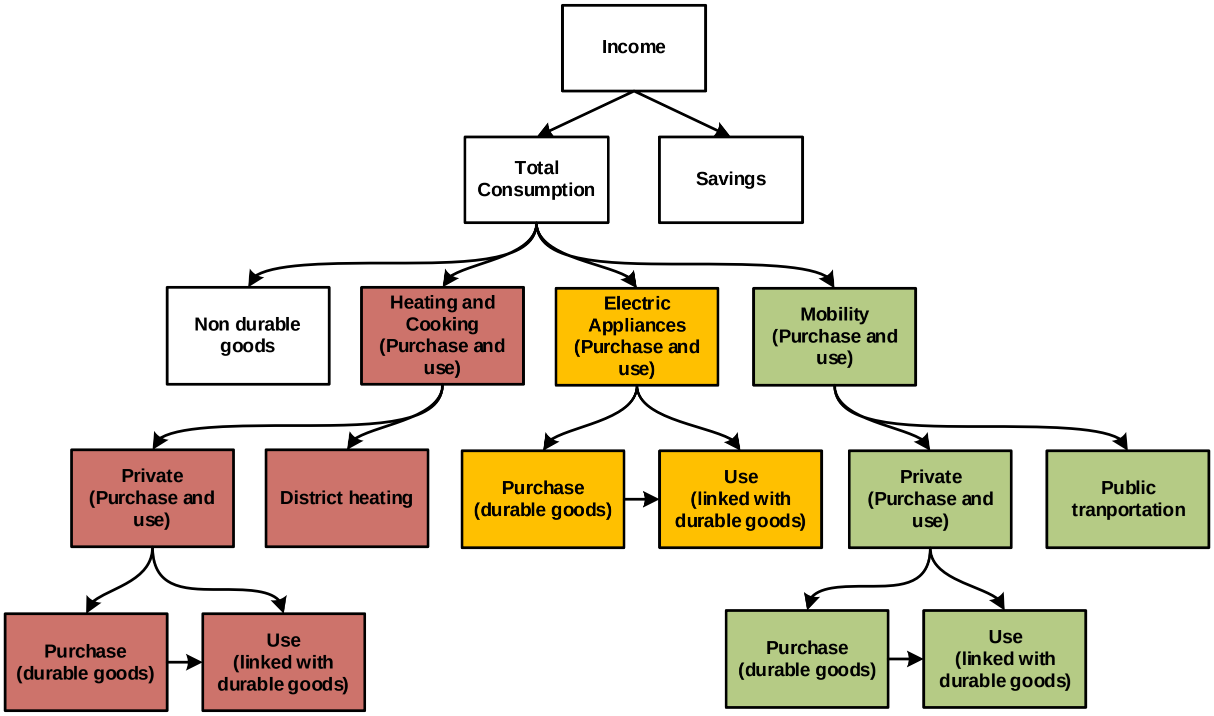
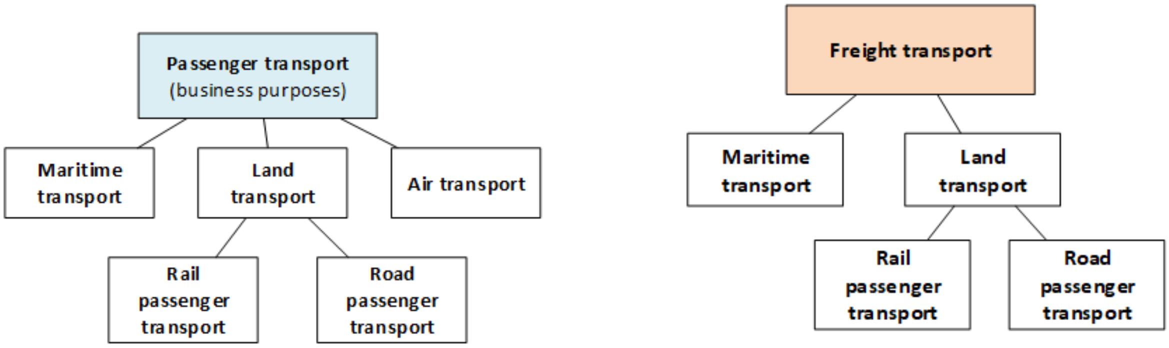


Figure 59: Suggested production decision tree for firms



Uncertainty

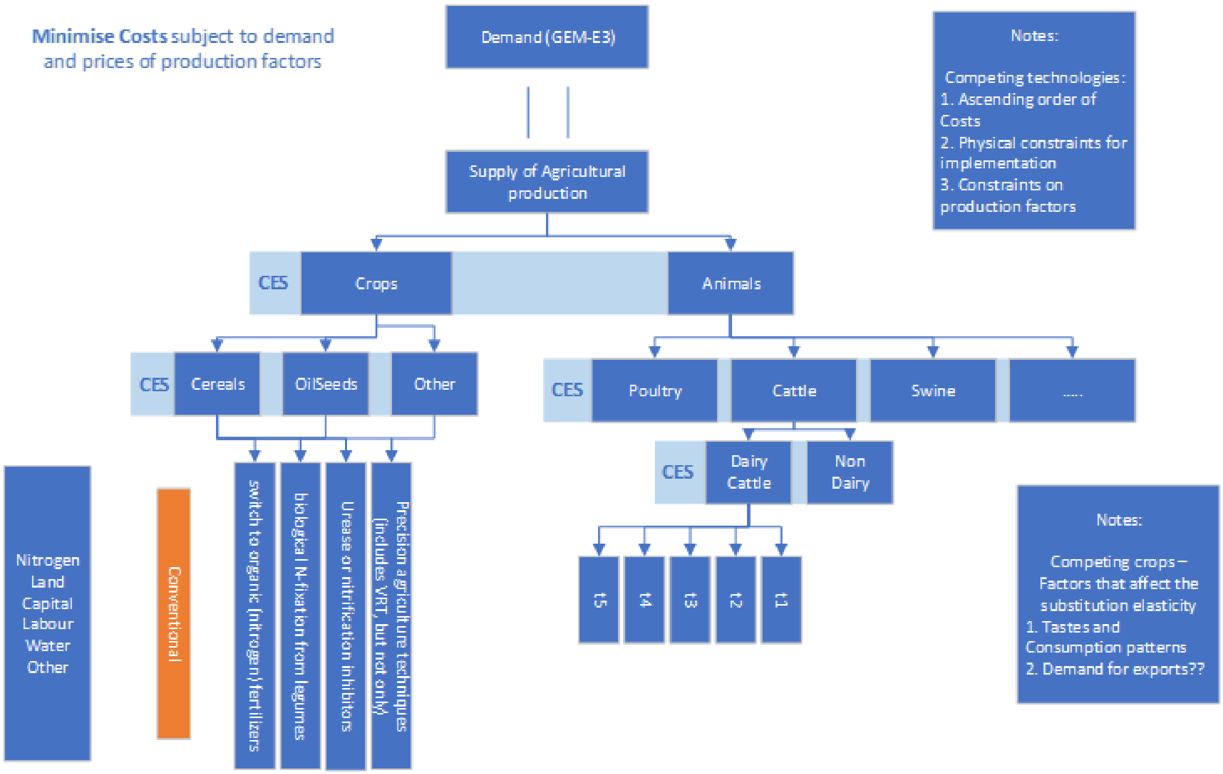
CGE model results are largely dependent on the selected elasticities (income, price, labour, substitution, trade etc.) It is suggested to add a sensitivity analysis module to the GEM-E3-SI model able to perform the following:

- Creation of distributions for key elasticities / learning rates or any other parameter to which the model is sensitive
- Automated multiple runs of the model for selected values of the distribution
- Requirement: Short Running time
- Visualizations of the results

Agriculture

In Slovenia the contribution of direct emissions from agriculture, excluding emissions resulting from fuel use, fertilizer production, and agriculturally-induced land use change, is estimated at 10–12% of total GHG emissions. Agriculture is considered a hard to abate sector as the mitigation options are limited and upper bounded. The existing version of the GEM-E3 model has aggregate emission factors for CO2, CH4 and N2O while abatement options are proxied by marginal abatement cost curve. This approach lacks the detail on abatement options and sources of GHG emissions A bottom up module that can be soft linked with the GEM-E3-SI can improve the analysis on costs and abatement potential of the agricultural sector

Figure 60: Suggested decision tree approach for households



7 References

Armington, P.S. (1969), A theory of demand for products distinguished by place of production, *International Monetary Fund Staff Papers* 16, 159–78.

Arrow, K. & Debreu, G., (1954). Existence of an equilibrium for a competitive economy, *Econometrica*, 22 (3), 265-290.

Baldwin, R.E. (1992), Measurable dynamic gains from trade, *Journal of Political Economy*, 100 (1), 162–174.

Dewatripont, M. & Ginsburgh, V. (Eds.), (1994), European Economic Integration: A Challenge in a Changing World. Amsterdam: North Holland.

Grossman, G., M. & Helpman,E., (1991), Trade, knowledge spillovers, and growth, *European Economic Review*, 35(2-3), 517-526.

Helpman, E. and P. Krugman (1985), Market Structure and International Trade. MIT Press.

Jorgenson, D. W. (1984). Econometric methods for Applied General Equilibrium Analysis. In H Scarf and J. B. Shoven (eds), Applied General Equilibrium Analysis, pp. 139-203, Cambridge University Press: Cambridge.

Mansur, A. and J. Whalley (1984), Numerical specification of applied general equilibrium models: estimation, calibration, and data, in Scarf and Shoven (eds.) Applied general equilibrium analysis, Cambridge University Press.

McDougall, R., A., (2006), Construction of the trade data, In Dimaranan, Betina V., (Ed.). Global trade, assistance, and production: The GTAP 6 data base, Center for Global Trade Analysis, Purdue University.

McClelland Robert, Mok Shannon, "A Review of Recent Research on Labor Supply Elasticities",Working Paper Series,Congressional Budget Office,Washington, D.C., (2012) Working Paper 2012-12

Rutherford, T. (2009). Constant Elasticity of Substitution Preferences: Utility, Demand, Indirect Utility and Expenditure Functions. ETH Zurich, lecture notes.

Stone, R. (1954), Linear expenditure system and demand analysis: An application to the pattern of British demand, *Economic Journal,* 64, 511-527.

Venables, T. & Baldwin, R., (1995), Regional economic integration. In: Grossmann, G. M. and Rogoff, K., (eds.) Handbook of International Economics. Vol.3. Handbooks in economics 3. Elsevier, Amsterdam.

8 ANNEX

Model code in GAMS

ENVIRONMENTAL MODULE

etxenv(ghga,br,er,an)..	Carbon price - Firms

```
  TXENV(ghga,br,er,an) =E= SUM(cc, P_PCLUB(ghga,cc,an)*swclubbr(ghga,br,er,cc,an))
                 + (txem(ghga,br,er,an)*P_WPI(an)/p_wpi0)*swtxexobr(ghga,br,er,an);
```

etxenvhdg(ghga,fn,er,an)..	Carbon price - Household

```
  TXENVHDG(ghga,fn,er,an) =E= SUM(cc, P_PCLUB(ghga,cc,an)*swclubh(ghga,fn,er,cc,an))
                   + (txemhdg(ghga,fn,er,an)*P_WPI(an)/p_wpi0)*swtxexoh(ghga,fn,er,an);
```

eemmbr(ghga,br,er,an)..	Emissions - Firms

```
  A_EMMBR(ghga,br,er,an) =E= sum(prene, bec(ghga,prene,br,er,an)*aer(prene,br,er,an)*
                                  eaf(prene,br,er,an)*(1 - Transport_IntUse(br,er)) * A_IO(prene,br,er,an))
                  + mec(ghga,br,er,an) *(1 - Transport_IntUse(br,er)) * A_XD(br,er,an)
                  - AAtot(ghga,br,er,an) * mec(ghga,br,er,an) *(1 - Transport_IntUse(br,er)) * A_XD(br,er,an);
```

eemmbr_int(ghga,br,er,an)$Transport_IntUse(br,er)..	Emissions – Firms (International Transport)

```
  A_EMMBR_INT(ghga,br,er,an) =E= sum(prene, bec(ghga,prene,br,er,an)*aer(prene,br,er,an)*
                                  eaf(prene,br,er,an)*Transport_IntUse(br,er)*A_IO(prene,br,er,an))
                    + mec(ghga,br,er,an) * Transport_IntUse(br,er) * A_XD(br,er,an)
                    - AAtot(ghga,br,er,an) * mec(ghga,br,er,an) * Transport_IntUse(br,er) * A_XD(br,er,an);
```

eEMMHLND(ghga,fn,er,an)..	Emissions - Households

```
A_EMMHLND(ghga,fn,er,an) =E= sum(prfuel, bech(ghga,prfuel,fn,er,an)*aerh(prfuel,fn,er,an)*
                                         eafh(prfuel,fn,er,an)*A_HCFVPV(prfuel,fn,er,an));
```

stockAA(ghga,br,er,rtime)$(mac1(er,ghga,br,rtime) and an(rtime))..	Abatement

```
AAtot(ghga,br,er,rtime)  =e= AAincr(ghga,br,er,rtime) + AAtot(ghga,br,er,rtime-1) *
                               (1 - AAdepr(ghga,rtime))**(ttime(rtime)-ttime(rtime-1));
```

incrAA(ghga,br,er,rtime)$(mac1(er,ghga,br,rtime) and an(rtime))..	Increamental Abatement

```
AAincr(ghga,br,er,rtime) =e= AA(ghga,br,er,rtime) - AAtot(ghga,br,er,rtime-1) *
                               (1 - AAdepr(ghga,rtime))**(ttime(rtime)-ttime(rtime-1));
```

eaa(ghga,br,er,an)$mac1(er,ghga,br,an)..	Marginal cost of abetament

```
MCGHG(ghga,br,er,an)  =l=  TXENV(ghga,br,er,an);
```

emcghg(ghga,br,er,an)$mac1(er,ghga,br,an)..	Marginal cost curve of abetament

```
MCGHG(ghga,br,er,an) =e= P_WPI(an)/p_wpi0*mac1(er,ghga,br,an)*[exp(AA(ghga,br,er,an)) - 1];
```

ecabavv(ghga,br,er,an)$mac1(er,ghga,br,an)..	Average Cost of abatement

```
 CABAVV(ghga,br,er,an) =E= (P_WPI(an)/p_wpi0 * mac1(er,ghga,br,an)*
                             (exp(AA(ghga,br,er,an))-1 -AA(ghga,br,er,an))/sum(pr, tabcost(ghga,pr,er,an)*P_IO(pr,er,an)));
```

eabiov(pr,br,er,an)..	Expenditure on intermediate inputs to abate emissions

```
  ABIOV(pr,br,er,an) =E= sum(poghg,tabcost(poghg,pr,er,an)*CABAVV(poghg,br,er,an)*AAincr(poghg,br,er,an)*
                          mec(poghg,br,er,an)*(1 - Transport_IntUse(br,er))*A_XD(br,er,an));
```

edempereu(ghga,cc,an)..	Demand of permits

```
  DEMPEREU(ghga,cc,an) =E=   sum((er,br), A_EMMBR(ghga,br,er,an)*swclubbr(ghga,br,er,cc,an))
                             + sum((er,fn), A_EMMHLND(ghga,fn,er,an)*swclubh(ghga,fn,er,cc,an));
```

eequiccag(cc,an)$(smax((ghg,br,er), swclubbr(ghg,br,er,cc,an)) or smax((ghg,fn,er), swclubh(ghg,fn,er,cc,an)))..	Market clearance

```
  sum(ghg, supperfeu(ghg,cc,an)) =G= sum(ghg, DEMPEREU(ghg,cc,an));
```

eequicc(ghg,cc,an)..	Carbon price

```
  P_PCLUB(ghg,cc,an) =E= P_PCLUBAG(cc,an);
```

epd(br,er,an)..	Unit cost of production

```
  P_PD(br,er,an) =E= P_PDBSR(br,er,an) - PSALE(br,er,an)
                           + sum(poghg,((1-AAtot(poghg,br,er,an))*TXENV(poghg,br,er,an)
                           +AAincr(poghg,br,er,an)*sum(pr, tabcost(poghg,pr,er,an)*P_IO(pr,er,an))*CABAVV(poghg,br,er,an)
                            )*mec(poghg,br,er,an)*(1 - Transport_IntUse(br,er)));
```

esalep(ghga,br,er,an)$((swonpor(ghga,br,er,an) eq 1) and sum(byear, A_EMMBR.l(ghga,br,er,byear)))..	Permit Sale

```
  SALEP(ghga,br,er,an)  =E=   [A_EMMBR(ghga,br,er,an) * TXENV(ghga,br,er,an)  ]$(swPrimAlloc(ghga,br,er,an) eq 0)
     + [ (1-dporbr(ghga,br,er,an))*emmbr_2005(ghga,br,er)*TXENV(ghga,br,er,an)
                                                  *SWONPOR(ghga,br,er,an)]$(swPrimAlloc(ghga,br,er,an) = 1)
     + [ nallo_br(ghga,br,er,an)*TXENV(ghga,br,er,an)*SWONPOR(ghga,br,er,an)]$(swPrimAlloc(ghga,br,er,an) = 2);
```

epsale(br,er,an)$(sum(ghga, swonpor(ghga,br,er,an)) ne 0)..	Impact of free allowances in unit cost of production

```
PSALE(br,er,an)  =E= [sum(ghga,   SALEP(ghga,br,er,an)*(1 - SHAUCTBR(br,er,an)))/A_XD(br,er,an)]$(SWUPR(br,er,an) eq 0);
```

ebusat(ghga,br,er,an)$(swonpor(ghga,br,er,an) ne 0 and sum(byear, A_EMMBR.l(ghga,br,er,byear)) ne 0)..	Net Purchases by Branches

```
  BUSAT(ghga,br,er,an) =E=  A_EMMBR(ghga,br,er,an)* TXENV(ghga,br,er,an) - SALEP(ghga,br,er,an);
```

esaleph(ghga,fn,er,an)$(swonporh(ghga,fn,er,an) ne 0 and A_EMMHLND.l(ghga,fn,er,byear) ne 0)..	Permit Sale

```
  SALEPH(ghga,fn,er,an)   =E=   [ A_EMMHLND(ghga,fn,er,an)*SWONPORH(ghga,fn,er,an)*
                                 (SUM(CC, P_PCLUB(ghga,CC,AN) * SWCLUBH(ghga,fn,ER,CC,AN))
                               + (txemhdg(ghga,fn,er,an)*P_WPI(an)/p_wpi0)*swtxexoh(ghga,fn,er,an))
                                                                         ]$(not swPrimAllocH(ghga,fn,er,an))
                              + [ (1-dporh(ghga,fn,er,an))*emmhlnd_2005(ghga,fn,er)*
                                  swonporh(ghga,fn,er,an)*sum(cc, P_PCLUB(ghga,cc,an) * swclubh(ghga,fn,er,cc,an))
                                                                         ]$(swPrimAllocH(ghga,fn,er,an) = 1)
                              + [nallo_hh(ghga,fn,er,an)*SWONPORH(ghga,fn,er,an)*
                                 sum(cc, P_PCLUB(ghga,cc,an) * swclubh(ghga,fn,er,cc,an))
                                                                         ]$(swPrimalloch(ghga,fn,er,an) = 2);
```

ebusath(ghga,fn,er,an)$(swonporh(ghga,fn,er,an) ne 0)..	Net purchases of households

```
  BUSATH(ghga,fn,er,an) =E=  A_EMMHLND(ghga,fn,er,an)*swonporh(ghga,fn,er,an)* TXENVHDG(ghga,fn,er,an)
                              - SALEPH(ghga,fn,er,an);
```

PRICES

esales(prtrd,er,an)..	Derived Domestic Output Prices

```
  P_XD(prtrd,er,an) =E=   P_PD(prtrd,er,an) + (txsub(prtrd,er,an)+TAX_REC_PS(er,an))
                          + P_IMP(prtrd,er,an)*rtnc(prtrd,er,an);
```

esupply(br,er,an)..	Export output price

```
  P_PWE(br,er,an)  =E=    P_PD(br,er,an) + (txsub(br,er,an)+ TAX_REC_PS(er,an))
                          + P_IMP(br,er,an)*rtnc(br,er,an);
```

epy(pr,er,an)..	Basic input price by Armington function

```
 P_Y(pr,er,an)    =E=   [ (((1/ac(pr,er,an))*(delta(pr,er,an)**sigmax(pr,er,an)*P_IMP(pr,er,an)**(1-sigmax(pr,er,an))
                 + (1-delta(pr,er,an))**(sigmax(pr,er,an))*P_XD(pr,er,an)**(1-sigmax(pr,er,an)))
```

```
                 **(1/(1-sigmax(pr,er,an)))))$(ac(pr,er,an) ne 0)+P_XD(pr,er,an)$(ac(pr,er,an) eq 0)
                                                                        ]$(prtrd(pr) and (theta_dkav(pr,er,an) ne 0 ))
                + [ (P_IMP(pr,er,an)*rtxd(pr,er,an)
                + (P_PD(pr,er,an)+ (txsub(pr,er,an)+TAX_REC_PS(er,an))*P_WPI(an)/p_wpi0)*
                  (1-rtxd(pr,er,an)))
                                                                        ]$(prntrd(pr) and (theta_dkav(pr,er,an) ne 0))
                +    P_IMP(pr,er,an)                                    $(theta_dkav(pr,er,an) eq 0);
```

epio(pr,er,an)..	Intermediate input purchase price

```
  P_IO(pr,er,an) =E=   (txit(pr,er,an) + TAX_REC_GT(er,an))*P_WPI(an)/p_wpi0 + P_Y(pr,er,an);
```

epenpr(pr,br,er,an)$pren(pr)..	Intermediate input price for energy products including abatement

```
  P_ENPR(pr,br,er,an)  =E= ( P_IO(pr,er,an) + sum(poem, TXENV(poem,br,er,an)*bec(poem,pr,br,er,an)*aer(pr,br,er,an)*
              eaf(pr,br,er,an)*(1 - Transport_IntUse(br,er)))
           + (txsubnrj_Firms(pr,br,er,an) + txitnrj_Firms(pr,br,er,an)) *P_WPI(an)/p_wpi0                    $(prene(pr))
           + (P_IO(pr,er,an) + (txsubnrj_Firms(pr,br,er,an) + txitnrj_Firms(pr,br,er,an)) *P_WPI(an)/p_wpi0   )$(pr_ele(pr));
```

epel(br,er,an)..	Electricity price

```
  P_ELE(br,er,an) =E= sum(pr_ele, P_ENPR(pr_ele,br,er,an));
```

epgc(pr,er,an)..	Government purchase price

```
  P_GC(pr,er,an)  =E= (txit(pr,er,an) + TAX_REC_GT(er,an))*P_WPI(an)/p_wpi0 + P_Y(pr,er,an);
```

ephc(pr,er,an)$(a_hc0(pr,er))..	Consumer purchase price

```
  P_HC(pr,er,an)  =E= ((txit(pr,er,an) + TAX_REC_GT(er,an))*P_WPI(an)/p_wpi0 + P_Y(pr,er,an))*(1+txvat(pr,er,an));
```

epinv(br,er,an)..	Investment purchase price

```
  P_INV(br,er,an) =E=  p_inv0(br,er)*(
                sum(pr, tinvpv(pr,br,er,an)*P_INVP(pr,er,an)/p_invp0(pr,er)      )$(sum(pr, tinvpv(pr,br,er,an)) ne 0)
                +1.                                                              $(sum(pr ,tinvpv(pr,br,er,an)) eq 0));
```

epinvp(pr,er,an)..	Investment purchase price

```
  P_INVP(pr,er,an) =E= (txit(pr,er,an) + TAX_REC_GT(er,an))*P_WPI(an)/p_wpi0 +P_Y(pr,er,an);
```

epc(er,an)..	Consumer price index

```
  P_PC(er,an) =E= sum(fn, P_HCFV(fn,er,an) * A_HCFV(fn,er,an))/sum(fn, p_hcfv0(fn,er) * A_HCFV(fn,er,an));
```

LABOUR MARKET

epl(sk_type,pr,er,an)..	Factor Price

```
  P_LAV(sk_type,pr,er,an) * (1- (txfss_sk(sk_type,pr,er,an)  + TAX_REC_SS(er,an)))
                          =E=   tl(sk_type,pr,er,an)*P_WRMEAN(sk_type,er,an)*XLNUM(sk_type,er,an);
```

exlnum(sk_type,er,an)..	Adjustment on average price

```
  XLNUM(sk_type,er,an)    =E=   sum(pr, A_LAV(sk_type,pr,er,an))/sum(pr, A_LAV(sk_type,pr,er,an)*tl(sk_type,pr,er,an));
```

EPOPV(sk_type,er,an)..	Labour supply

```
  A_POPV(sk_type,er,an)    =E=   TotLabFrc(sk_type,er,an);
```

EEQUILAB(sk_type,er,an)..	Market Clearance

```
  RT_UNRT(sk_type,er,an)   =E=   1- SUM(pr, A_LAV(sk_type,pr,er,an))/A_POPV(sk_type,er,an);
```

EQEFFICIENCYWAGE(sk_type,er,an)$(swunrt(sk_type,er,an)=0)..	Efficiency wage

```
  P_WRMEAN(sk_type,er,an) =e= P_PC(er,an)/p_pc0(er)*[alpha_wc(sk_type,er,an) +  beta_wc(sk_type,er,an)
                             /(RT_UNRT(sk_type,er,an)- edelta_wc(sk_type,er,an))**sigma_wc(sk_type,er,an)];
```

CAPITAL MARKET

epk(pr,er,an)..	Factor Price

```
   P_KAV(pr,er,an)    =E=  P_KNOKM(pr,er,an)                                    $(swonkm(an) eq 0)
                          + [ anakm(pr,er,an)          *P_KNAKM(er,an)]         $(swonkm(an) eq 1);
```

eequiki(br,er,rtime)$(theta_dkav(br,er,rtime) ne 0 and swonkm(rtime) eq 0 and an(rtime))..	Capital stock fix and sector specific

```
   A_KAV(br,er,rtime)              =E=   A_KAVC(br,er,rtime-1);
```

eequikc(er,rtime)$(swonkm(rtime) eq 1 and an(rtime))..	Capital stock fix and tradable between sectors

```
   sum(pr, anakm(pr,er,byear)* A_KAV(pr,er,rtime))        =E=   sum(pr, anakm(pr,er,byear) * A_KAVC(pr,er,rtime-1));
```

FIRMS

exd(br,er,an)$(a_xd0(br,er,an))..	Unit cost of production

```
   P_PDBSR(br,er,an)    =e=
*    non-resource sectors
       +[ + p_pdbsr0(br,er,an)*(     theta_dkle(br,er,an)*(P_KLE(br,er,an)/p_kle0(br,er,an))**(1-sn1(br,er,an))/
                        [tfp(br,er,an)*tfpexo(br,er,an)]**(1-sn1(BR,ER,AN))
                      + theta_dtrama(br,er,an)  *(P_TRAMA(br,er,an)  /p_trama0(br,er,an))**(1-sn1(br,er,an))/
                        [tfp(br,er,an)*tfpexo(br,er,an)]**(1-sn1(BR,ER,AN))
                     )**(1/(1-sn1(br,er,an)))
        ]$(prdf(br))

*    resource sectors
       +[ + p_pdbsr0(br,er,an)*(    theta_dresf(br,er,an)  * (P_RESF(br,er,an)/p_resf0(br,er,an))**(1-sn0(br,er,an))/
                       [tfp(br,er,an)*tfpexo(br,er,an)]**(1-sn0(br,er,an))
                      + theta_dklem(br,er,an)  * (P_KLEMRS(br,er,an)/p_klemrs0(br,er,an))**(1-sn0(br,er,an))/
                       [tfp(br,er,an)*tfpexo(br,er,an)]**(1-sn0(br,er,an))
                     )**(1/(1-sn0(br,er,an)))
        ]$prrs(br)

*    refineries
       +[ + p_pdbsr0(br,er,an)*(   sum(prrs, theta_dio(prrs,br,er,an)*(P_IO(prrs,er,an)/ p_io0(prrs,er,an))**(1-sn0(br,er,an))/
                      [tfp(br,er,an)*tfpexo(br,er,an)]**(1-sn0(br,er,an)))
                     + theta_dklem(br,er,an)* (P_KLEM(br,er,an)/p_klem0(br,er,an))**(1-sn0(br,er,an))/
                      [tfp(br,er,an)*tfpexo(br,er,an)]**(1-sn0(br,er,an))
                    )**(1/(1-sn0(br,er,an)))
        ]$prref(br)

*    power producing technologies (Leontief)
       +[ + p_pdbsr0(br,er,an)*(
          + theta_dkav(br,er,an)    *(P_KAV(br,er,an) /p_kav0(br,er,an) )
                /[tfp(br,er,an)*tfpexo(br,er,an)]*exp(-tgk(br,er,an))
          + sum(sk_type, theta_dl_hs(sk_type,br,er,an)*(P_LAV(sk_type,br,er,an)/p_lav0(sk_type,br,er,an))
                /[tfp(br,er,an)*tfpexo(br,er,an)]*exp(-tgl(sk_type,br,er,an)))
          + sum(sk_type, theta_dl_ls(sk_type,br,er,an)*(P_LAV(sk_type,br,er,an)/p_lav0(sk_type,br,er,an))
                /[tfp(br,er,an)*tfpexo(br,er,an)]*exp(-tgl(sk_type,br,er,an)))
          + sum(pr$(not pren(pr)),  theta_dio(pr,br,er,an)*(P_IO(pr,er,an)/p_io0(pr,er,an))
               /[tfp(br,er,an)*tfpexo(br,er,an)]*exp(-tgm(pr,br,er,an)) )
          + sum(pr$(    pr_ele(pr)),theta_dio(pr,br,er,an)*(P_ENPR(pr,br,er,an)/p_io0(pr,er,an))
               /[tfp(br,er,an)*tfpexo(br,er,an)]*exp(-tgen(pr,br,er,an)) )
          + sum(pr$(    prene(pr)), theta_dio(pr,br,er,an)*(P_ENPR(pr,br,er,an)/p_io0(pr,er,an))
               /[tfp(br,er,an)*tfpexo(br,er,an)]*exp(-tgen(pr,br,er,an)) )       )
        ]$prtec(br)
*    electricity sector (Leontief)
       +[ tpxd(br,er,an) *(P_TECH(br,er,an) + P_DIST(br,er,an)) / [tfp(br,er,an)*tfpexo(br,er,an)]
         ]$pr_ele(br);
```

epKLE(pr,er,an)$((prdf(pr) or prref(pr)) and a_xd0(pr,er,an))..	2nd level for default sectors and 3rd level for refineries Unit cost for the Capital labor Energy bundle

```
  P_KLE(pr,er,an) =E= p_kle0(pr,er,an)*( theta_dkl(pr,er,an) *(P_KL(pr,er,an) /p_kl0(pr,er,an) )**(1-sn2(pr,er,an))
                                        + theta_deng(pr,er,an)*(P_ENG(pr,er,an)/p_eng0(pr,er,an))**(1-sn2(pr,er,an))
                                         )**(1/(1-sn2(pr,er,an)));
```

epm(br,er,an)$((prdf(br) or prrs(br) or prref(br)) and a_xd0(br,er,an) and a_ma0(br,er,an))..	2nd level for default sectors, 3rd level for refineries and 4th level for Resources Unit cost for the material inputs bundle

```
  P_MA(br,er,an) =E=
* non energy sectors and resource sectors
           +[ p_ma0(br,er,an)*( sum(prmane, theta_dmpr(prmane,br,er,an)*(P_IO(prmane,er,an)/p_io0(prmane,er,an)
                   *exp(-tgm(prmane,br,er,an)))**(1-sn3(br,er,an))))**(1/(1-sn3(br,er,an)))
            ]$(prdf(br) or prrs(br))

* refineries
           +[ p_ma0(br,er,an)*( sum(prma, theta_dmpr(prma,br,er,an)*(P_IO(prma,er,an)/p_io0(prma,er,an)
                   *exp(-tgm(prma,br,er,an))) **(1-sn3(br,er,an))))**(1/(1-sn3(br,er,an)))
            ]$(prref(br));
```

eptech(pr_ele,er,an)..	2nd level: power supply Unit cost of electricity power generation

```
  P_TECH(pr_ele,er,an)  =e= +[sum(prtec,  dio(prtec,pr_ele,er,an)*P_IO(prtec,er,an))]$(swxdiotec = 0)
                            +[sum(prtec, xdio(prtec,er,an)       *P_IO(prtec,er,an))]$(swxdiotec = 1);
```

epdist(pr_ele,er,an)..	2nd level: power supply Unit cost of power distribution

```
  P_DIST(pr_ele,er,an)  =e= p_dist0(pr_ele,er,an)*( theta_dkav(pr_ele,er,an) *(P_KAV(pr_ele,er,an)/p_kav0(pr_ele,er,an) *
                              exp(-tgk(pr_ele,er,an)))
           + sum(sk_type, theta_dl_hs(sk_type,pr_ele,er,an)*(P_LAV(sk_type,pr_ele,er,an)/p_lav0(sk_type,pr_ele,er,an) *
                              exp(-tgl(sk_type,pr_ele,er,an))))
           + sum(sk_type, theta_dl_ls(sk_type,pr_ele,er,an)*(P_LAV(sk_type,pr_ele,er,an)/p_lav0(sk_type,pr_ele,er,an) *
                              exp(-tgl(sk_type,pr_ele,er,an))))
           + sum(br$([not prtec(br)] and [not pren(br)]), theta_dio(br,pr_ele,er,an)    *(P_IO(br,er,an)    /p_io0(br,er,an) ))
           + sum(pren,      theta_dio(pren,pr_ele,er,an)*(P_ENPR(pren,pr_ele,er,an)/p_io0(pren,er,an))));
```

epklem(pr,er,an)$(prref(pr))..	2nd level for refineries Unit cost of Capital Labor Energy Materials bundle

```
  P_KLEM(pr,er,an) =e=    p_klem0(pr,er,an)*(theta_dkle(pr,er,an)*(P_KLE(pr,er,an)/p_kle0(pr,er,an))**(1-sn1(pr,er,an))
                        + theta_dtrama(pr,er,an)  *(P_TRAMA(pr,er,an) /p_trama0(pr,er,an) )**(1-sn1(pr,er,an))
                         )**(1/(1-sn1(pr,er,an)));
```

epklemrs(pr,er,an)$(prrs(pr))..	2nd level for resources Unit cost of Capital Labor Energy Materials bundle

```
  P_KLEMRS(pr,er,an) =e= p_klemrs0(pr,er,an)*(
                               theta_dkl(pr,er,an)*       (P_KLRS(pr,er,an)/p_klrs0(pr,er,an))**(1-snrs1(pr,er,an))
                             + theta_dmaen(pr,er,an) *(P_MAEN(pr,er,an)/p_maen0(pr,er,an))**(1-snrs1(pr,er,an))
                         )**(1/(1-snrs1(pr,er,an)));
```

epkl(pr,er,an)$((prdf(pr) or prref(pr)) and a_kl0(pr,er,an))..	3rd level for default sectors, 4th level for refineries Unit cost of Value added (Capital and Labour)

```
  P_KL(pr,er,an)  =e= p_kl0(pr,er,an)*( theta_dklskld(pr,er,an)    *(P_KLSKLD(pr,er,an)/p_klskld0(pr,er,an))**(1-sn4(pr,er,an))
                   + sum(sk_type, theta_dl_ls(sk_type,pr,er,an)*(P_LAV(sk_type,pr,er,an)/p_lav0(sk_type,pr,er,an)*
                     exp(-tgl(sk_type,pr,er,an)))**(1-sn4(pr,er,an))))**(1/(1-sn4(pr,er,an)));
```

epklskld(pr,er,an)$((prdf(pr) or prref(pr)) and a_klskld0(pr,er,an))..	4th level for default sectors, 5th level for refineries Unit cost of Capital and high skilled bundle

```
  P_KLSKLD(pr,er,an) =e= p_klskld0(pr,er,an)*( theta_dkav(pr,er,an)   * (P_KAV(pr,er,an)  /p_kav0(pr,er,an)  *
                                   exp(-tgk(pr,er,an)     ))**(1-sn7(pr,er,an))
                                + sum(sk_type, theta_dl_hs(sk_type,pr,er,an) * (P_LAV(sk_type,pr,er,an)/p_lav0(sk_type,pr,er,an)*
                                   exp(-tgl(sk_type,pr,er,an)))**(1-sn7(pr,er,an)))
                                   )**(1/(1-sn7(pr,er,an)));
```

epklrs(pr,er,an)$(prrs(pr))..	3rd level for resources Unit cost of Value added (Capital and Labour)

```
  P_KLRS(pr,er,an) =e=  p_klrs0(pr,er,an)*( theta_dklrsskld(pr,er,an) *
                                             (P_KLRSSKLD(pr,er,an)/p_klrsskld0(pr,er,an))**(1-sn4(pr,er,an))
                              + sum(sk_type, theta_dl_ls(sk_type,pr,er,an)*(P_LAV(sk_type,pr,er,an)/p_lav0(sk_type,pr,er,an)*
                                                                exp(-tgl(sk_type,pr,er,an)))**(1-sn4(pr,er,an)))
                                             )**(1/(1-sn4(pr,er,an)));
```

epklrsskld(pr,er,an)$(prrs(pr))..	4th level for resources Unit cost of Capital and high skilled bundle

```
  P_KLRSSKLD(pr,er,an)  =e= p_klrsskld0(pr,er,an)*( theta_dkav(pr,er,an) *
                                             (P_KAV(pr,er,an)  /p_kav0(pr,er,an)*exp(-tgk(pr,er,an)))**(1-sn7(pr,er,an))
                             + sum(sk_type, theta_dl_hs(sk_type,pr,er,an)*(P_LAV(sk_type,pr,er,an)/p_lav0(sk_type,pr,er,an)*
                                                                         exp(-tgl(sk_type,pr,er,an)))**(1-sn7(pr,er,an)))
                                            )**(1/(1-sn7(pr,er,an)));
```

epmaen(prrs,er,an)..	3rd level for resources Unit cost of Material and Energy bundle

```
  P_MAEN(prrs,er,an) =E= p_maen0(prrs,er,an)*(theta_dtrama(prrs,er,an)*
                                              (P_TRAMA(prrs,er,an)/p_trama0(prrs,er,an) )**(1-snrs2(prrs,er,an))
                                 +theta_de(prrs,er,an)   *(P_EN(prrs,er,an)/p_en0(prrs,er,an) )**(1-snrs2(prrs,er,an))
                                 +theta_dele(prrs,er,an) *(P_ELE(prrs,er,an)/p_ele0(prrs,er,an)*
                                                   exp(-sum(pr_ele,  tgen(pr_ele,prrs,er,an))))**(1-snrs2(prrs,er,an))
                                             )**(1/(1-snrs2(prrs,er,an)));
```

epe(br,er,an)$(prdf(br) or prrs(br) or prref(br))..	4th level for default sectors, resources and refineries Unit cost of fossil fuel energy bundle

```
  P_EN(br,er,an) =e= (p_en0(br,er,an)*( sum(prfuel, theta_depr(prfuel,br,er,an)*(P_ENPR(prfuel,br,er,an)
                           /p_io0(prfuel,er,an)*exp(-tgen(prfuel,br,er,an)))**(1-sn6(br,er,an))))**(1/(1-sn6(br,er,an)))
                            )$(theta_de(br,er,an)>0)
                          +1$(theta_de(br,er,an)=0);
```

epeng(pr,er,an)$((prdf(pr) or prref(pr)) and a_eng0(pr,er,an)) ..	3rd level for default sectors and refineries Unit cost of Energy bundle

```
  P_ENG(pr,er,an) =e= p_eng0(pr,er,an)*( theta_dele(pr,er,an)*(P_ELE(pr,er,an)/p_ele0(pr,er,an)*
                                                          exp(-sum(pr_ele, tgen(pr_ele,pr,er,an))))**(1-sn5(pr,er,an))
                                            + theta_de(pr,er,an) * (P_EN(pr,er,an) /p_en0(pr,er,an))**(1-sn5(pr,er,an))
                                            )**(1/(1-sn5(pr,er,an)));
```

ekav(pr,er,an)$a_kav0(pr,er,an)..	Demand for capital

```
  A_KAV(pr,er,an) =e= +[ theta_dkav(pr,er,an) * A_KLSKLD(pr,er,an) *
                              (p_klskld0(pr,er,an)/p_kav0(pr,er,an))*exp(tgk(pr,er,an)*(sn7(pr,er,an)-1))*
                              (P_KLSKLD(pr,er,an)/P_KAV(pr,er,an)*p_kav0(pr,er,an)/p_klskld0(pr,er,an) )**sn7(pr,er,an)
                 ]$((not prtec(pr)) and (not prrs(pr)) and (not pr_ele(pr)))
                +[ theta_dkav(pr,er,an)*(p_pdbsr0(pr,er,an)/p_kav0(pr,er,an))*A_XD(pr,er,an)*exp(tgk(pr,er,an)*(-1))
                  *[tfp(pr,er,an)*tfpexo(pr,er,an)]**(-1)
                 ]$prtec(pr)
                +[ a_kav0(pr,er,an)*exp(tgk(pr,er,an)*(-1))*A_DIST(pr,er,an)/a_dist0(pr,er,an)
                 ]$pr_ele(pr)
```

```
                   +[ a_kav0(pr,er,an)*exp(tgk(pr,er,an)*(sn7(pr,er,an)-1))*A_KLRSSKLD(pr,er,an)/a_klrsskld0(pr,er,an)*
                     (P_KLRSSKLD(pr,er,an)/P_KAV(pr,er,an)*p_kav0(pr,er,an)/p_klrsskld0(pr,er,an) )**sn7(pr,er,an)
                    ]$prrs(pr);
```

ela(sk_type,pr,er,an)$a_lav0(sk_type,pr,er,an)..	Demand for labour

```
  A_LAV(sk_type,pr,er,an) =e=
           [ theta_dl_ls(sk_type,pr,er,an) * A_KL(pr,er,an) * (p_kl0(pr,er,an)/p_lav0(sk_type,pr,er,an))*
             exp(tgl(sk_type,pr,er,an)*(sn4(pr,er,an)-1))*
            (P_KL(pr,er,an)/P_LAV(sk_type,pr,er,an)* p_lav0(sk_type,pr,er,an)/p_kl0(pr,er,an))**sn4(pr,er,an)
                                              ]$((not prtec(pr)) and (not prrs(pr)) and (not pr_ele(pr))  and l_sk_type(sk_type))
          +[ theta_dl_hs(sk_type,pr,er,an) * A_KLSKLD(pr,er,an) * (p_klskld0(pr,er,an)/p_lav0(sk_type,pr,er,an))*
             exp(tgl(sk_type,pr,er,an)*(sn7(pr,er,an)-1))*
            (P_KLSKLD(pr,er,an)/P_LAV(sk_type,pr,er,an)* p_lav0(sk_type,pr,er,an)/p_klskld0(pr,er,an))**sn7(pr,er,an)
                                             ]$((not prtec(pr)) and (not prrs(pr)) and (not pr_ele(pr)) and h_sk_type(sk_type))
          +[ theta_dl_ls(sk_type,pr,er,an)*(p_pdbsr0(pr,er,an)/p_lav0(sk_type,pr,er,an))*A_XD(pr,er,an)*
             exp(tgl(sk_type,pr,er,an)*(-1))*[tfp(pr,er,an)*tfpexo(pr,er,an)]**(-1)
                                             ]$(prtec(pr) and l_sk_type(sk_type))
          +[ theta_dl_hs(sk_type,pr,er,an)*(p_pdbsr0(pr,er,an)/p_lav0(sk_type,pr,er,an))*A_XD(pr,er,an)*
             exp(tgl(sk_type,pr,er,an)*(-1))*[tfp(pr,er,an)*tfpexo(pr,er,an)]**(-1)
                                            ]$(prtec(pr) and h_sk_type(sk_type))
          +[ a_lav0(sk_type,pr,er,an)*exp(tgl(sk_type,pr,er,an)*(-1))*A_DIST(pr,er,an)/a_dist0(pr,er,an)
                                            ]$pr_ele(pr)
          +[ a_lav0(sk_type,pr,er,an)*exp(tgl(sk_type,pr,er,an)*(sn4(pr,er,an)-1))*A_KLRS(pr,er,an)/a_klrs0(pr,er,an)*
           (P_KLRS(pr,er,an)/P_LAV(sk_type,pr,er,an)* p_lav0(sk_type,pr,er,an)/p_klrs0(pr,er,an))**sn4(pr,er,an)
                                            ]$(prrs(pr) and l_sk_type(sk_type))
          +[ a_lav0(sk_type,pr,er,an)*exp(tgl(sk_type,pr,er,an)*(sn7(pr,er,an)-1))*A_KLRSSKLD(pr,er,an)/a_klrsskld0(pr,er,an)*
           (P_KLRSSKLD(pr,er,an)/P_LAV(sk_type,pr,er,an)* p_lav0(sk_type,pr,er,an)/p_klrsskld0(pr,er,an))**sn7(pr,er,an)
                                            ]$(prrs(pr) and h_sk_type(sk_type));
```

eresfv(prrs,er,an)..	Demand for reserves

```
  A_RESFV(prrs,er,an)  =e=  +a_resfv0(prrs,er,an)*A_XD(prrs,er,an)/a_xd0(prrs,er,an)*
                  (P_PDBSR(prrs,er,an)/P_RESF(prrs,er,an)*p_resf0(prrs,er,an)/p_pdbsr0(prrs,er,an))**sn0(prrs,er,an)
                   *[tfp(prrs,er,an)*tfpexo(prrs,er,an)]**(sn0(prrs,er,an)-1);
```

ekle(pr,er,an)$((prdf(pr) or prref(pr)) and a_xd0(pr,er,an))..	2nd level for default sectors and 3rd level for refineries Demand for capital labor energy bundle

```
  A_KLE(pr,er,an) =e=  +[theta_dkle(pr,er,an)*(p_pdbsr0(pr,er,an)/p_kle0(pr,er,an))*A_XD(pr,er,an)*
                         (P_PDBSR(pr,er,an)/P_KLE(pr,er,an)*p_kle0(pr,er,an)/p_pdbsr0(pr,er,an))
                       **sn1(pr,er,an) *[tfp(pr,er,an)*tfpexo(pr,er,an)]**(sn1(pr,er,an)-1)     ]$prdf(pr)
                       +[theta_dkle(pr,er,an)*(p_klem0(pr,er,an)/p_kle0(pr,er,an))*A_KLEM(pr,er,an)*
                         (P_KLEM(pr,er,an)/P_KLE(pr,er,an)*p_kle0(pr,er,an)/p_klem0(pr,er,an))**sn1(pr,er,an)]$prref(pr);
```

etrama(pr,er,an)$(a_trama0(pr,er,an) and (prdf(pr) or prref(pr) or prrs(pr)))..	2nd level for default sectors, 3rd level for refineries and 4th level for resources Demand for transport and material bundle

```
  A_TRAMA(pr,er,an)  =e= + [theta_dtrama(pr,er,an)*(p_pdbsr0(pr,er,an)/p_trama0(pr,er,an))*A_XD(pr,er,an)*
                 (P_PDBSR(pr,er,an)/P_TRAMA(pr,er,an)*p_trama0(pr,er,an)/p_pdbsr0(pr,er,an))**sn1(pr,er,an)
                 * [tfp(pr,er,an)*tfpexo(pr,er,an)]**(sn1(pr,er,an)-1)                                   ]$prdf(pr)
                 + [theta_dtrama(pr,er,an)*(p_maen0(pr,er,an)/p_trama0(pr,er,an))*A_MAEN(pr,er,an)*
                 (P_MAEN(pr,er,an)/P_TRAMA(pr,er,an)*p_trama0(pr,er,an)/p_maen0(pr,er,an))**snrs2(pr,er,an) ]$prrs(pr)
                 + [theta_dtrama(pr,er,an)*(p_klem0(pr,er,an)/p_trama0(pr,er,an))*A_KLEM(pr,er,an)*
                  (P_KLEM(pr,er,an)/P_TRAMA(pr,er,an)*p_trama0(pr,er,an)/p_klem0(pr,er,an))**sn1(pr,er,an)      ]$prref(pr);
```

edist(pr_ele,er,an)..	2nd level for power supply Demand for power transmission and distribution

```
  A_DIST(pr_ele,er,an) =e= tpxd(pr_ele,er,an) * A_XD(pr_ele,er,an)/[tfp(pr_ele,er,an)*tfpexo(pr_ele,er,an)];
```

etech(pr_ele,er,an)..	2nd level for power supply Demand for power generation

```
   A_TECH(pr_ele,er,an) =e= tpxd(pr_ele,er,an) * A_XD(pr_ele,er,an)/[tfp(pr_ele,er,an)*tfpexo(pr_ele,er,an)];
```

eklem(pr,er,an)$(prref(pr))..	2nd level for refineries Demand for Capital Labor Energy Materials bundle

```
   A_KLEM(pr,er,an) =e= + theta_dklem(pr,er,an)*(p_pdbsr0(pr,er,an)/p_klem0(pr,er,an))*A_XD(pr,er,an)*
                  (P_PDBSR(pr,er,an)/P_KLEM(pr,er,an)*p_klem0(pr,er,an)/p_pdbsr0(pr,er,an))**sn0(pr,er,an)
                  *[tfp(pr,er,an)*tfpexo(pr,er,an)]**(sn0(pr,er,an)-1);
```

eklemrs(pr,er,an)$(prrs(pr))..	2nd level for resources Demand for Capital Labor Energy Materials bundle

```
   A_KLEMRS(pr,er,an) =e= +  a_klemrs0(pr,er,an) * A_XD(pr,er,an)/a_xd0(pr,er,an)*
                    (P_PDBSR(pr,er,an)/P_KLEMRS(pr,er,an)*p_klemrs0(pr,er,an)/p_pdbsr0(pr,er,an))**sn0(pr,er,an)
                    *[tfp(pr,er,an)*tfpexo(pr,er,an)]**(sn0(pr,er,an)-1);
```

ekl(pr,er,an)$(prdf(pr) or prref(pr))..	3rd level for default sectors and 4th level for refineries Demand for Value added (Capital and labor bundle)

```
   A_KL(pr,er,an)  =e= + theta_dkl(pr,er,an)*A_KLE(pr,er,an)*(p_kle0(pr,er,an)/p_kl0(pr,er,an))*
                              (P_KLE(PR,ER,AN)/P_KL(pr,er,an)*p_kl0(pr,er,an)/p_kle0(pr,er,an))**sn2(pr,er,an);
```

eklrs(pr,er,an)$(prrs(pr))..	3rd level for resources Demand for Value added (Capital and labor bundle)

```
   A_KLRS(pr,er,an)  =e= a_klrs0(pr,er,an)*A_KLEMRS(pr,er,an)/a_klemrs0(pr,er,an)*
                           (P_KLEMRS(pr,er,an)/P_KLRS(pr,er,an)*p_klrs0(pr,er,an)/p_klemrs0(pr,er,an))**snrs1(pr,er,an);
```

emaen(prrs,er,an)..	3rd level for resources Demand for Materials and Energy bundle

```
   A_MAEN(prrs,er,an) =e= + a_maen0(prrs,er,an)* A_KLEMRS(prrs,er,an)/a_klemrs0(prrs,er,an)*
                 (P_KLEMRS(prrs,er,an)/P_MAEN(prrs,er,an)*p_maen0(prrs,er,an)/p_klemrs0(prrs,er,an) )**snrs1(prrs,er,an);
```

eeng(pr,er,an)$((prdf(pr) or prref(pr)) and a_xd0(pr,er,an) and theta_deng(pr,er,an))..	3rd level for default sectors and refineries Demand for Energy bundle

```
   A_ENG(pr,er,an) =e=  theta_deng(pr,er,an)*A_KLE(pr,er,an)*(p_kle0(pr,er,an)/p_eng0(pr,er,an))
                              *(P_KLE(pr,er,an)/ P_ENG(pr,er,an)*p_eng0(pr,er,an)/p_kle0(pr,er,an) )**sn2(pr,er,an);
```

eenl(pr,er,an)$(prdf(pr) or prrs(pr) or prref(pr))..	4th level for default sectors, resources and refineries Demand for Electricity

```
   A_ELE(pr,er,an) =e= +[theta_dele(pr,er,an)*(p_eng0(pr,er,an)/p_ele0(pr,er,an))*A_ENG(pr,er,an)
                 *(P_ENG(pr,er,an)/P_ELE(pr,er,an)*p_ele0(pr,er,an)/p_eng0(pr,er,an))**sn5(pr,er,an)
                 *exp((sum(pr_ele,  tgen(pr_ele,pr,er,an)))*(sn5(pr,er,an)-1))                ]$(prdf(pr) or prref(pr))
                +[theta_dele(pr,er,an)*(p_maen0(pr,er,an)/p_ele0(pr,er,an))*A_MAEN(pr,er,an)
                 *(P_MAEN(pr,er,an)/P_ELE(pr,er,an)*p_ele0(pr,er,an)/p_maen0(pr,er,an))**snrs2(pr,er,an)
                 *exp((sum(pr_ele,  tgen(pr_ele,pr,er,an) ))*(snrs2(pr,er,an)-1))             ]$prrs(pr);
```

een(pr,er,an)$(prdf(pr) or prrs(pr) or prref(pr))..	4th level for default sectors, resources and refineries Demand for fossil fuel energy bundle

```
   A_EN(pr,er,an) =e= +[theta_de(pr,er,an)*(p_eng0(pr,er,an)/p_en0(pr,er,an))*A_ENG(pr,er,an)
                *(P_ENG(pr,er,an)/P_EN(pr,er,an)*p_en0(pr,er,an)/p_eng0(pr,er,an))**sn5(pr,er,an)       ]$(prdf(pr) or prref(pr))
               +[theta_de(pr,er,an)*(p_maen0(pr,er,an)/p_en0(pr,er,an))*A_MAEN(pr,er,an)
                *(P_MAEN(pr,er,an)/P_EN(pr,er,an)*p_en0(pr,er,an)/p_maen0(pr,er,an))**snrs2(pr,er,an)]$prrs(pr);
```

eiovtot(pr,br,er,an)..	Demand for intermediate input

```
   A_IO(pr,br,er,an) =e= +[ + (
theta_dmpr(pr,br,er,an)*(p_ma0(br,er,an)/p_io0(pr,er,an))*A_MA(br,er,an)*(P_MA(br,er,an)/P_IO(pr,er,an)
                   *p_io0(pr,er,an) /p_ma0(br,er,an))**sn3(br,er,an)* exp(tgm(pr,br,er,an)*(sn3(br,er,an)-1)))
                 $(a_ma0(br,er,an) and prmane(pr) and a_xd0(br,er,an))
```

```
                      + (
theta_depr(pr,br,er,an)*(p_en0(br,er,an)/p_io0(pr,er,an))*A_EN(br,er,an)*(P_EN(br,er,an)/P_ENPR(pr,br,er,an)
               *p_io0(pr,er,an) /p_en0(br,er,an))**sn6(br,er,an)* exp((tgen(pr,br,er,an))*(sn6(br,er,an)-1)))
             $(a_en0(br,er,an)  and prfuel(pr)   and a_xd0(br,er,an))
             + (a_io0(pr,br,er,an)* A_ELE(br,er,an)/a_ele0(br,er,an))
             $(a_ele0(br,er,an) and pr_ele(pr)    and a_xd0(br,er,an))
                                                                              ]$(prdf(br) and (not prtra(pr)))
            +[ +
(theta_dmpr(pr,br,er,an)*(p_ma0(br,er,an)/p_io0(pr,er,an))*A_MA(br,er,an)*(P_MA(br,er,an)/P_IO(pr,er,an)
              *p_io0(pr,er,an)/p_ma0(br,er,an))**sn3(br,er,an)* exp(tgm(pr,br,er,an)*(sn3(br,er,an)-1)))
             $(a_ma0(br,er,an) and prmane(pr) and a_xd0(br,er,an))
             +
(theta_depr(pr,br,er,an)*(p_en0(br,er,an)/p_io0(pr,er,an))*A_EN(br,er,an)*(P_EN(br,er,an)/P_ENPR(pr,br,er,an)
              *p_io0(pr,er,an)/p_en0(br,er,an))**sn6(br,er,an)* exp((tgen(pr,br,er,an))*(sn6(br,er,an)-1)))
             $(a_en0(br,er,an) and prfuel(pr) and a_xd0(br,er,an))
             + (a_io0(pr,br,er,an)*A_ELE(br,er,an)/a_ele0(br,er,an))
             $(a_ele0(br,er,an) and pr_ele(pr)  and a_xd0(br,er,an))
                                                                              ]$(prrs(br))
            +[ +
(theta_dmpr(pr,br,er,an)*(p_ma0(br,er,an)/p_io0(pr,er,an))*A_MA(br,er,an)*(P_MA(br,er,an)/P_IO(pr,er,an)
              *p_io0(pr,er,an)/p_ma0(br,er,an))**sn3(br,er,an)* exp(tgm(pr,br,er,an)*(sn3(br,er,an)-1)))
             $( a_ma0(br,er,an)   and prma(pr) and a_xd0(br,er,an))
             +
(theta_dio(pr,br,er,an)*(p_pdbsr0(br,er,an)/p_io0(pr,er,an))*A_XD(br,er,an)*(P_PDBSR(br,er,an)/P_IO(pr,er,an)
              *p_io0(pr,er,an)/p_pdbsr0(br,er,an))**sn0(br,er,an) *[tfp(br,er,an)*tfpexo(br,er,an)]**(sn0(br,er,an)-1))
             $( a_fuel0(br,er,an)  and prrs(pr) and a_xd0(br,er,an))
             +
(theta_depr(pr,br,er,an)*(p_en0(br,er,an)/p_io0(pr,er,an))*A_EN(br,er,an)*(P_EN(br,er,an)/P_ENPR(pr,br,er,an)
             *p_io0(pr,er,an) /p_en0(br,er,an))**sn6(br,er,an)* exp((tgen(pr,br,er,an))*(sn6(br,er,an)-1)))
             $( a_en0(br,er,an)   and prfuel(pr)    and a_xd0(br,er,an))
             + (a_io0(pr,br,er,an)*A_ELE(br,er,an)/a_ele0(br,er,an))
             $( a_ele0(br,er,an)  and pr_ele(pr)     and a_xd0(br,er,an))
                                                                              ]$(prref(br))
           +[ + (theta_dio(pr,br,er,an)*(p_pdbsr0(br,er,an)/p_io0(pr,er,an))*A_XD(br,er,an)*exp(tgm(pr,br,er,an)*(-1))
             *[tfp(br,er,an)*tfpexo(br,er,an)]**(-1))
             $( prmane(pr)    and a_xd0(br,er,an))
            + (theta_dio(pr,br,er,an)*(p_pdbsr0(br,er,an)/p_io0(pr,er,an))*A_XD(br,er,an)*exp((tgen(pr,br,er,an))*(-1))
             *[tfp(br,er,an)*tfpexo(br,er,an)]**(-1))
             $( prfuel(pr)    and a_xd0(br,er,an))
            + (theta_dio(pr,br,er,an)*(p_pdbsr0(br,er,an)/p_io0(pr,er,an))*A_XD(br,er,an)*exp((tgen(pr,br,er,an))*(-1))
             *[tfp(br,er,an)*tfpexo(br,er,an)]**(-1))
             $( pr_ele(pr)     and a_xd0(br,er,an))                                ]$(prtec(br))
          +[ + (a_io0(pr,br,er,an)*A_DIST(br,er,an) /a_dist0(br,er,an) *exp(tgm(pr,br,er,an)*(-1)))
             $(prmane(pr) and a_xd0(br,er,an))
            + (a_io0(pr,br,er,an)*A_DIST(br,er,an) /a_dist0(br,er,an))
             $(prfuel(pr) and a_xd0(br,er,an))
            + (a_io0(pr,br,er,an)*A_DIST(br,er,an) /a_dist0(br,er,an))
             $(pr_ele(pr) and a_xd0(br,er,an))
            + (dio(pr,br,er,an)*A_TECH(br,er,an)) $(prtec(pr)  and a_xd0(br,er,an) and (swxdiotec =0))
            + (xdio(pr,er,an)  *A_TECH(br,er,an))  $(prtec(pr)  and a_xd0(br,er,an) and (swxdiotec =1))
                                                                              ]$(pr_ele(br))
          +[ a_io0(pr,br,er,an)*A_TRALAND(br,er,an) /a_traland0(br,er,an)*exp(tgm(pr,br,er,an)*(-1))
                                                              ]$(pr_land(pr) and (a_traland0(br,er,an)  ne 0))
          +[ a_io0(pr,br,er,an)*A_TRAAIR(br,er,an)  /a_traair0(br,er,an)   *exp(tgm(pr,br,er,an)*(-1))
                                                              ]$(pr_air(pr)  and (a_traair0(br,er,an)   ne 0))
          +[ a_io0(pr,br,er,an)*A_TRAWATER(br,er,an)/a_trawater0(br,er,an) *exp(tgm(pr,br,er,an)*(-1))
                                                               ]$(pr_wtr(pr)  and (a_trawater0(br,er,an) ne 0));
```

eklrsskld(pr,er,an)$prrs(pr)..	4th level for resources Demand for capital and high skilled labor bundle

```
A_KLRSSKLD(pr,er,an) =e=  a_klrsskld0(pr,er,an)* A_KLRS(pr,er,an)/a_klrs0(pr,er,an)*
                                    (P_KLRS(pr,er,an)/ P_KLRSSKLD(pr,er,an)*p_klrsskld0(pr,er,an)/p_klrs0(pr,er,an))**sn4(pr,er,an);
```

eklskld(pr,er,an)$((prdf(pr) or prref(pr)) and a_klskld0(pr,er,an))..	4th level for default sectors and refineries Demand for capital and high skilled labor bundle

```
A_KLSKLD(pr,er,an)  =e=   theta_dklskld(pr,er,an) * A_KL(pr,er,an) * (p_kl0(pr,er,an)/p_klskld0(pr,er,an))*
                                      (P_KL(pr,er,an)/P_KLSKLD(pr,er,an)*p_klskld0(pr,er,an)/p_kl0(pr,er,an))**sn4(pr,er,an);
```

exdiotec(prtec,er,an)$(swxdiotec = 1)..	Demand for power generation technologies

```
XDIO(prtec,er,an) =e=       sum(pr_ele,  dio(prtec,pr_ele,er,an))*(p_io0(prtec,er,an)/P_IO(prtec,er,an))**stec(er,an)
                    /sum(prtecc,  sum(pr_ele,dio(prtecc,pr_ele,er,an))*(p_io0(prtecc,er,an)/P_IO(prtecc,er,an))**stec(er,an));
```

INVESTMENT

einvv(br,er,rtime)$(an(rtime))..	Investment demand

```
A_INV(br,er,rtime) =E=  [ A_KAV(br,er,rtime)*a0inv(br,er,rtime)*
                          ((P_KAV(br,er,rtime)/(P_INV(br,er,rtime)*((RLTLREU(rtime)*RLTLR(er,rtime))
                         + decl(br,er,rtime))))**(sninv(br,er,rtime)*a1inv(br,er,rtime))
                          * (1+stgr(br,er,rtime))-1+decl(br,er,rtime))            ]$(euc27(er) and (not swtec(br,er,rtime))))
                       +  [ A_KAV(br,er,rtime)*a0inv(br,er,rtime)*
                           ((P_KAV(br,er,rtime)/(P_INV(br,er,rtime)*((RLTLR(er,rtime))
                         +decl(br,er,rtime))))**(sninv(br,er,rtime)*a1inv(br,er,rtime))
                          * (1+stgr(br,er,rtime))-1+decl(br,er,rtime))            ]$((not euc27(er)) and (not swtec(br,er,rtime))))
                       +  [ exo_pg_investments(br,er,rtime)/P_INV(br,er,rtime)]                    $(swtec(br,er,rtime))
                        + exo_investements(br,er,rtime);
```

einvpv(pr,br,er,an)$(tinvpv(pr,br,er,an))..	Investment demand by commodity

```
A_INVP(pr,br,er,an) =E= tinvpv(pr,br,er,an)*(p_inv0(br,er)/p_invp0(pr,er))*A_INV(br,er,an);
```

einv(se,er,an)..	Investment by institutional sector

```
V_INV(se,er,an) =E=   [
              + tcinv(se,er,an)* sum(pr, P_INV(pr,er,an)*A_INV(pr,er,an))                  ]$(sameas(se,"H"))
             + [ sum(pr, build_energysave_f_renov(pr,er,an) * sum(br, es_renov_expenditures(br,er,an)))
              + sum(pr, build_energysave_f_equip(pr,er,an) * sum(br, es_equip_expenditures(br,er,an)))
              + tcinv(se,er,an)* sum(pr, P_INV(pr,er,an)*A_INV(pr,er,an))                  ]$(sameas(se,"F"))
             + [ sum(fn, es_h_expenditures(fn,er,an)) * (1 - sh_finance(er,an))
              + tcinv(se,er,an)* sum(pr, P_INV(pr,er,an)*A_INV(pr,er,an))                  ]$(sameas(se,"G"))
             + [ tcinv(se,er,an)* sum(pr, P_INV(pr,er,an)*A_INV(pr,er,an))                 ]$(sameas(se,"W"));
```

ekavc(pr,er,rtime)$(an(rtime))..	Law of motion for capital

```
A_KAVC(pr,er,rtime) =E= ( (1-decl(pr,er,rtime))**(ttime1(rtime)-ttime1(rtime-1))*A_KAV(pr,er,rtime)
               + ((1-(1-decl(pr,er,rtime))**(ttime1(rtime)-ttime1(rtime-1)))/decl(pr,er,rtime))
                   * A_INV(pr,er,rtime)
               )$(theta_dkav(pr,er,rtime) ne 0);
```

FINAL CONSUMPTION

eydisp(er,an)..	Disposable Income

```
V_YDISP(er,an)  =E=    sum(fa,V_FSEFA("H",fa,er,an))   + sum(sr, V_FSESE("H",sr,er,an)) - sum(sr,V_FSESE(sr,"H",er,an))
                        - sum(fn, es_h_expenditures(fn,er,an)) * sh_finance(er,an);
```

etsave(er,an)..	Private consumption

```
V_HCDTOT(er,an) =E= [ sum(fn, P_HCFV(fn,er,an)*chcfv(fn,er,an))
             + (stp(er,an)/(RLTLREU(an)*RLTLR(er,an)*RLTLRWORLD(an)))
             * (V_YDISP(er,an) - sum(fn, P_HCFV(fn,er,an)*chcfv(fn,er,an)))  ]$euc27(er)
                   +    [ sum(fn, P_HCFV(fn,er,an)*chcfv(fn,er,an))
             + (stp(er,an)/(RLTLR(er,an)*RLTLRWORLD(an)))
```

```
                 * (V_YDISP(er,an) - sum(fn, P_HCFV(fn,er,an)*chcfv(fn,er,an))) ]$(not euc27(er));
```

egcv(pr,er,an)..	Public consumption

```
A_GC(pr,er,an) =E=  [(gctv(er,an))$(swgc(er,an)=0)
               + sh_gctv(er,an)* (sum(br, P_HC.l(br,er,byear)*A_HC(br,er,an)
                                  + sum(pr1, P_INVP.l(pr1,er,byear)*A_INVP(pr1,br,er,an))
                                  + P_GC.l(br,er,byear)* A_GC(br,er,an)
                                  + P_PWE.L(br,er,byear)*A_YVTWR(br,er,an)
                                  + P_PWE.l(br,er,byear)*[SUM(CR, A_EXPO(br,er,cr,an))]
                                  - P_IMP.l(br,er,byear)*A_IMP(br,er,AN)
                                 ))$(swgc(er,an)=1)
               ]*tgcv(pr,er,an);
```

TOTAL ECONOMY

exdtot(br,er,an)..	Total production in volume

```
A_XD(br,er,an) =E= [A_XXD(br,er,an) + sum(cr, A_EXPO(br,er,cr,an))                                   ]$(prtrd(br))
             + [A_Y(br,er,an)   + sum(cr, A_EXPO(br,er,cr,an)) + A_YVTWR(br,er,an) - A_IMP(br,er,an)]$(prntrd(br));
```

eydem(pr,er,an)..	Total Domestic Demand

```
A_Y(pr,er,an) =E= SUM(br, A_IO(pr,br,er,an) + ABIOV(pr,br,er,an) + A_INVP(pr,br,er,an)) + A_HC(pr,er,an)
                   + A_GC(pr,er,an)  + A_BUILD_ENERGYSAVE_H(pr,er,an) + A_BUILD_ENERGYSAVE_F(pr,er,an);
```

eabsor(prtrd,er,an)..	Armington Allocation

```
A_XXD(prtrd,er,an) =E= [(A_Y(prtrd,er,an)*ac(prtrd,er,an)**(sigmax(prtrd,er,an)-1)
                  *(1-delta(prtrd,er,an))**(sigmax(prtrd,er,an))
                  *(P_Y(prtrd,er,an)/P_XD(prtrd,er,an))**(sigmax(prtrd,er,an)))]$(ac(prtrd,er,an) ne 0)
                 + A_Y(prtrd,er,an)                                          $(ac(prtrd,er,an) eq 0);
```

INTERNATIONAL TRADE

epwxo(pr,cs,cr,an)..	Bilateral import prices

```
P_IMPO(pr,cs,cr,an) =E= P_PWE(pr,cr,an) + sum(prtra, cif_vtwr(prtra,pr,cs,cr,an)*P_TR(prtra,an))
                              + txduto(pr,cs,cr,an)*P_WPI(an)/p_wpi0;
```

epimpl(pr,er,an)..	Import price

```
P_IMP(pr,er,an) =E= ((sum(cr, beta(pr,er,cr,an)**(sigmai(pr,er,an))*(P_IMPO(pr,er,cr,an))**(1-sigmai(pr,er,an))))
                    **(1/(1-sigmai(pr,er,an)))
                 )$(sum(cr,beta(pr,er,cr,an)) ne 0)
               + 1.$(sum(cr,beta(pr,er,cr,an)) eq 0);
```

eexpol(br,cr,cs,an)..	Export quantities

```
A_EXPO(br,cr,cs,an) =E=  A_IMPO(br,cs,cr,an);
```

costmin(prtrd,er,an)..	Demand for competitive imports

```
A_IMP_C(prtrd,er,an)    =E= (A_Y(prtrd,er,an)*ac(prtrd,er,an)**(sigmax(prtrd,er,an)-1)
                    *delta(prtrd,er,an)**sigmax(prtrd,er,an)*(P_Y(prtrd,er,an)/P_IMP(prtrd,er,an))**sigmax(prtrd,er,an))
                    $(ac(prtrd,er,an) ne 0);
```

eimpnc(prtrd,er,an)..	Demand for non-competitive imports

```
A_IMP_NC(prtrd,er,an) =E= rtnc(prtrd,er,an)*A_XD(prtrd,er,an);
```

eimpl(br,cr,an)..	Total imports

```
A_IMP(br,cr,an) =E=  A_IMP_NC(br,cr,an)
             + (A_IMP_C(br,cr,an)                             )$(prtrd(br))
             + (A_Y(br,cr,an)*rtxd(br,cr,an)                  )$(prntrd(br) and (theta_dkav(br,cr,an) ne 0))
             + (A_Y(br,cr,an) + sum(er, A_EXPO(br,cr,er,an))  )$(prntrd(br) and (theta_dkav(br,cr,an) eq 0));
```

eimpo(br,cr,cs,an)..	Bilateral import quantities

```
  A_IMPO(br,cr,cs,an) =E= A_IMP(br,cr,an) *(P_IMP(br,cr,an)/P_IMPO(br,cr,cs,an)*beta(br,cr,cs,an))**(sigmai(br,cr,an));
```

INTERNATIONAL TRANSPORT SERVICE

zpf_VST(prtra,an)..	Zero profit of international transport services

```
     sum(cr, theta_vst(prtra,cr,an)*(P_PWE(prtra,cr,an)/p_pwe0(prtra,cr))) =G=   P_TR(prtra,an);
```

mkt_VST(prtra,an)..	Market clearance

```
    vtag(prtra,an)*A_YVST(prtra,an)  =G=  sum((cr,cs,br), A_EXPO(br,cr,cs,an)*cif_vtwr(prtra,br,cs,cr,an));
```

def_YVTWR(prtra,er,an)..	Demand for international transport services

```
   A_YVTWR(prtra,er,an) =E=   A_YVST(prtra,an)*vtag(prtra,an)*theta_vst(prtra,er,an);
```

INSTITUTIONAL TRANSFERS

efgrbtotl(gvb,pr,er,an)..	Government tax income

```
  V_FGRB(gvb,pr,er,an) =E=
* Duties
   +[ +sum(cr, txduto(pr,er,cr,an) * P_WPI(an)/p_wpi0 * A_IMPO(pr,er,cr,an) )                  ]$sameas(gvb,"DUT")
* Subsidies
   +[ ((TXSUB(pr,er,an) + TAX_REC_PS(er,an))*P_WPI(an)/p_wpi0)*A_XD(pr,er,an)
      + sum(fn, txsubnrj_HC(pr,fn,er,an)*P_WPI(an)/p_wpi0 * A_HCFVPV(pr,fn,er,an))
      + sum(br, txsubnrj_Firms(pr,br,er,an)*P_WPI(an)/p_wpi0 * A_IO(pr,br,er,an))            ]$sameas(gvb,"SUB")
* Indirect tax
   +[ (txit(pr,er,an) + TAX_REC_GT(er,an))*P_WPI(an)/p_wpi0
          *(  sum(br, (A_IO(pr,br,er,an) + ABIOV(pr,br,er,an))) + A_GC(pr,er,an) + A_HC(pr,er,an)
           + sum(br,  A_INVP(pr,br,er,an)) + A_BUILD_ENERGYSAVE_H(pr,er,an) + A_BUILD_ENERGYSAVE_F(pr,er,an))
     + sum(fn,  txitnrj_HC(pr,fn,er,an)*P_WPI(an)/p_wpi0 * A_HCFVPV(pr,fn,er,an))
     + sum(br,  txitnrj_Firms(pr,br,er,an) *P_WPI(an)/p_wpi0 * A_IO(pr,br,er,an))              ]$sameas(gvb,"IT")
* VAT
   +[ (txvat(pr,er,an))
          *( (P_Y(PR,ER,AN)+(txit(pr,er,an) + TAX_REC_GT(er,an))*
             P_WPI(an)/p_wpi0)*A_HC(pr,er,an))                                                 ]$sameas(gvb,"VAT")
*Environmental Taxes
   +[   ( sum(ghga, TXENV(ghga,pr,er,an)* A_EMMBR(ghga,pr,er,an))
       - (SUM(ghga, (1 - SHAUCTBR(pr,er,an))*SALEP(ghga,pr,er,an)))
      + sum((fn,ghga), TXENVHdg(ghga,fn,er,an)*[bech(ghga,pr,fn,er,an)*aerh(pr,fn,er,an)*eafh(pr,fn,er,an)*
                              A_HCFVPV(pr,fn,er,an)]))$prfuel(pr)

     + ( sum(ghga,TXENV(ghga,pr,er,an)*A_EMMBR(ghga,pr,er,an))
       - (SUM(ghga, (1 - SHAUCTBR(pr,er,an))*SALEP(ghga,pr,er,an)))
       )$(not prfuel(pr))
                                                                                               ]$sameas(gvb,"ENV");
```

efgrstot(gvs,se,er,an)..	Government revenues from sectors

```
  V_FGRS(gvs,se,er,an) =E=  [sum((br,sk_type), (txfss_sk(sk_type,br,er,an) –
                 TAX_REC_SS(er,an))* V_VA(sk_type,br,er,an))                        ]$(sameas(gvs,"ss") and sameas(se,"F"))
                         +  [sum((br,sk_type), (txhss_sk(sk_type,er,an) * (1-(txfss_sk(sk_type,br,er,an) –
                TAX_REC_SS(er,an))))* V_VA(sk_type,br,er,an))                       ]$(sameas(gvs,"ss") and sameas(se,"H"))
                        +  [txdirtaxf(er,an)  * (sum(br, txfsefa(se,"CAP",er,an) * V_VA("CAP",br,er,an)) +
                 Property_Income(se,er)*P_WPI(an)/p_wpi0)                           ]$(sameas(gvs,"dt") and sameas(se,"F"))
                        +  [txdirtaxh(er,an) * ( sum((br,fa), txfsefa(se,fa,er,an)* V_VA(fa,br,er,an)) +
                 Property_Income(se,er)*P_WPI(an)/p_wpi0
                        - sum((br,sk_type), (txhss_sk(sk_type,er,an) * (1-(txfss_sk(sk_type,br,er,an) –
                 TAX_REC_SS(er,an)))* V_VA(sk_type,br,er,an)))
                        + sum(br, txfsefa("F","CAP",er,an) * V_VA("CAP",br,er,an)) * txdividh(er,an)    )
                                                                                    ]$(sameas(gvs,"dt") and sameas(se,"H"));
```

efsese(se,sr,er,an)..	Transfers between sectors

```
  V_FSESE(se,sr,er,an) =E=
* Dividends
    [  txdividh(er,an) * sum(br, txfsefa(sr,"CAP",er,an) * V_VA("CAP",br,er,an))   ]$(sameas(se,"H") and sameas(sr,"F"))
* Social Security Households and Firms  and Direct Taxes on Household Income
   +[  V_FGRS("SS","F",er,an) + V_FGRS("SS",sr,er,an) +  V_FGRS("DT",sr,er,an)     ]$(sameas(se,"G") and sameas(sr,"H"))
* Direct Taxes on Firms Income
   +[  V_FGRS("DT",sr,er,an)
     + txdividg(er,an) * sum(br, txfsefa(sr,"CAP",er,an) * V_VA("CAP",br,er,an))   ]$(sameas(se,"G") and sameas(sr,"F"))
* Transfers for increase in social benefits multiplied by the value of endownment
   +[  Social_Benefit(er,an) * actp_t(er,an) *P_WPI(an)/p_wpi0
     + (TAX_REC_HT(er,an))*actp_t(er,an)*P_WPI(an)/p_wpi0
     + sum((ghga,fn),(1-shaucth(ghga,er,an))*SALEPH(ghga,fn,er,an))
     + Property_Income(se,er)*P_WPI(an)/p_wpi0                           ]$(sameas(se,"H") and sameas(sr,"G"))
* Property Income
   +[  Property_Income(se,er)*P_WPI(an)/p_wpi0                           ]$(sameas(se,"F") and sameas(sr,"G"))
* World
   +[+ sum((fn,ghga),BUSATH(ghga,fn,er,an))
     + sum((br,ghga), BUSAT(ghga,br,er,an))                              ]$(sameas(se,"W") and sameas(sr,"G"));
```

evatot(fa,pr,er,an)..	Factor income by branch

```
  V_VA(fa,pr,er,an) =E=  [P_LAV(fa,pr,er,an)*A_LAV(fa,pr,er,an)            ]$(sk_type(fa))
                 + [P_KAV(pr,er,an)*A_KAV(pr,er,an)
                 + SUM(ghga, (1 - SHAUCTBR(pr,er,an))*SALEP(ghga,pr,er,an))$(SWUPR(pr,er,an) eq 1)
                                                                           ]$(sameas(fa,"cap"))
                 + [P_RESF(pr,er,an)*A_RESFV(pr,er,an)                     ]$(sameas(fa,"ntres"));
```

EFSEFAT(fa,er,an)..	Total factor income

```
  V_FSEFAT(fa,er,an) =E=  SUM(br, V_VA(fa,br,er,an));
```

efsefa(se,fa,er,an)..	Transfers from Factors to Sectors

```
  V_FSEFA(se,fa,er,an)   =E= txfsefa(se,fa,er,an)* sum(br, V_VA(fa,br,er,an));
```

efcftot(se,er,an)..	Final consumption

```
  V_FC(se,er,an)        =E= [ V_HCDTOT(er,an)                                 ]$(sameas(se,"H"))
                     + [ 0.                                                   ]$(sameas(se,"F"))
                     + [ sum(pr, P_GC(pr,er,an)*A_GC(pr,er,an) )              ]$(sameas(se,"G"))
                     + [ sum(pr, P_PWE(pr,er,an)*sum(cr, A_EXPO(pr,er,cr,an)))
                     +   sum(prtra, P_PWE(prtra,er,an)*A_YVTWR(prtra,er,an)) ]$(sameas(se,"W"))
;
```

esavel(se,er,an)..	Savings by sector

```
  V_SAVE(se,er,an)      =E= [ V_YDISP(er,an) - V_HCDTOT(er,an)       ]$(sameas(se,"H"))
                     + [ sum(fa, V_FSEFA(se,fa,er,an))
                       + sum(sr, V_FSESE(se,sr,er,an) - V_FSESE(sr,se,er,an) )
                       - V_FC(se,er,an)                              ]$(sameas(se,"F"))
                     + [ sum((gv,br), V_FGRB(gv,br,er,an))
                       + sum(fa, V_FSEFA(se,fa,er,an) )
                       + sum(sr, V_FSESE(se,sr,er,an) - V_FSESE(sr,se,er,an))
                       - V_FC(se,er,an)                              ]$(sameas(se,"G"))
                      + [ sum(br,      P_IMP(br,er,an) * A_IMP(br,er,an))
                        - sum(br,      V_FGRB("DUT",br,er,an))
                        + sum(fa, V_FSEFA(se,fa,er,an) )
                        + sum(sr, V_FSESE(se,sr,er,an) - V_FSESE(sr,se,er,an))
                        - V_FC(se,er,an)                             ]$(sameas(se,"W"));
```

esurpl(se,er,an)..	Surplus or deficit by sector

```
  V_SURPL(se,er,an)      =E=   V_SAVE(se,er,an) - V_INV(se,er,an);
```

evu(er,an)..	Total value added

```
  V_VU(er,an)         =E=   sum((br,fa),  V_VA(fa,br,er,an));
```

CLOSURES

eWPI(an)..	Macro Closure

```
sum((se,er), V_SAVE(se,er,an)) =e=  sum((se,er), V_INV(se,er,an));
```

eequiws(er,an)$(swonca(er,an) ne 0)..	Trade Balance by country

```
  V_SURPL("W",er,an) =E=   (surplwrffx(er,an) * V_VU(er,an) )$(swonca(er,an) = 1)
                         + (share_CA(er,an)   * V_VU(er,an) )$(swonca(er,an) = 2);
```

eequiwseu(an)$(swoncaeu(an) ne 0)..	Trade Balance of EU27

```
  sum(euc27, V_SURPL("W",euc27,an)) =E= surplwrffxeu(an)*sum(euc27, V_VU(euc27,an));
```

eequigid(er,an)$(sum(recopt, recscheme(recopt,er,an)) ne 0)..	Public budget

```
  V_SURPL("G",er,an)   =E=   surplgrffx(er,an)*V_VU(er,an);
```

eequigid_HT(er,an)$(recscheme("HT",er,an))..	Recycling option: Lump sum transfer

```
   TAX_REC_HT(er,an)*actp_t(er,an)*P_WPI(an)/p_wpi0 =e= recscheme("HT",er,an) * PB_GAP(er,an);
```

eequigid_GT(er,an)$(recscheme("GT",er,an))..	Recycling option: General taxation

```
    sum(pr, TAX_REC_GT(er,an)*P_WPI(an)/p_wpi0
        *(  sum(br, (A_IO(pr,br,er,an) + ABIOV(pr,br,er,an))) + A_GC(pr,er,an) + A_HC(pr,er,an)
          + sum(br,  A_INVP(pr,br,er,an)) + A_BUILD_ENERGYSAVE_H(pr,er,an) + A_BUILD_ENERGYSAVE_F(pr,er,an)))
  + sum(pr, txvat(pr,er,an) * TAX_REC_GT(er,an) * P_WPI(an)/p_wpi0 *A_HC(pr,er,an))
   =e= - recscheme("GT",er,an) * PB_GAP(er,an);
```

eequigid_PS(er,an)$(recscheme("PS",er,an))..	Recycling option: Production subsidy

```
  sum(pr, TAX_REC_PS(er,an) * P_WPI(an)/p_wpi0 * A_XD(pr,er,an)) =e=  - recscheme("PS",er,an) * PB_GAP(er,an);
```

eequigid_SS(er,an)$(recscheme("SS",er,an))..	Recycling option: Social security contribution

```
   [sum((br,sk_type), (TAX_REC_SS(er,an)* V_VA(sk_type,br,er,an)))]
 +  [sum((br,sk_type), (- txhss_sk(sk_type,er,an) * TAX_REC_SS(er,an)* V_VA(sk_type,br,er,an)))]
 +  [txdirtaxh(er,an)* (sum((br,sk_type), txhss_sk(sk_type,er,an) * TAX_REC_SS(er,an)* V_VA(sk_type,br,er,an)))]
  =e= - recscheme("SS",er,an) * PB_GAP(er,an);
```

BUSINESS TRANSPORT SUBMODEL

eptrama(pr,er,an)$(a_trama0(pr,er,an) and (prdf(pr) or prrs(pr) or prref(pr)))..	Unit cost of transport and material bundle

```
  P_TRAMA(pr,er,an) =E= p_trama0(pr,er,an)* (theta_dtrans(pr,er,an) * (P_TRANS(pr,er,an)/p_trans0(pr,er,an))
                                           + theta_dm(pr,er,an) * P_MA(pr,er,an)/p_ma0(pr,er,an));
```

etrans(pr,er,an)$(a_trans0(pr,er,an) and (prdf(pr) or prrs(pr) or prref(pr)))..	Demand for the transport bundle

```
  A_TRANS(pr,er,an) =E= theta_dtrans(pr,er,an)*(p_trama0(pr,er,an)/p_trans0(pr,er,an)) * A_TRAMA(pr,er,an);
```

ema(pr,er,an)$(prdf(pr) or prrs(pr) or prref(pr))..	Unit cost of material bundle

```
  A_MA(pr,er,an)    =E=  theta_dm(pr,er,an)*(p_trama0(pr,er,an)/p_ma0(pr,er,an))  * A_TRAMA(pr,er,an);
```

eptrans(pr,er,an)$(a_trans0(pr,er,an) and (prdf(pr) or prrs(pr) or prref(pr)))..	Unit cost of transport bundle

```
  P_TRANS(pr,er,an)    =e= p_trans0(pr,er,an)*(
                      theta_dtraland(pr,er,an)  *  (P_TRALAND(pr,er,an) /p_traland0(pr,er,an) )**(1-sigmatra(pr,er,an))
                    + theta_dtrawater(pr,er,an) *  (P_TRAWATER(pr,er,an)/p_trawater0(pr,er,an))**(1-sigmatra(pr,er,an))
                    + theta_dtraair(pr,er,an)   *  (P_TRAAIR(pr,er,an)  /p_traair0(pr,er,an)  )**(1-sigmatra(pr,er,an))
                                                   )**(1/(1-sigmatra(pr,er,an)));
```

etraland(pr,er,an)$(a_traland0(pr,er,an) and (prdf(pr) or prrs(pr) or prref(pr)))..	Demand for the land transport

```
  A_TRALAND(pr,er,an)  =E= theta_dtraland(pr,er,an) * (p_trans0(pr,er,an)/p_traland0(pr,er,an)) * A_TRANS(pr,er,an) *
                    (P_TRANS(pr,er,an)/P_TRALAND(pr,er,an) *p_traland0(pr,er,an)  /p_trans0(pr,er,an))**sigmatra(pr,er,an);
```

eptraland(pr,er,an)$(a_traland0(pr,er,an) and (prdf(pr) or prrs(pr) or prref(pr)))..	Unit cost of land transport

```
  P_TRALAND(pr,er,an)  =e= P_IO(pr_land,er,an)*exp(tgm(pr_land,pr,er,an)*(-1));
```

etrawater(pr,er,an)$(prdf(pr) or prrs(pr) or prref(pr))..	Demand for the water transport

```
  A_TRAWATER(pr,er,an) =E= theta_dtrawater(pr,er,an)* (p_trans0(pr,er,an)/p_trawater0(pr,er,an))* A_TRANS(pr,er,an) *
                      (P_TRANS(pr,er,an)/P_TRAWATER(pr,er,an)*p_trawater0(pr,er,an) /p_trans0(pr,er,an))**sigmatra(pr,er,an);
```

eptrawater(pr,er,an)$(prdf(pr) or prrs(pr) or prref(pr))..	Unit cost of water transport

```
  P_TRAWATER(pr,er,an) =e= P_IO(pr_wtr,er,an)*exp(tgm(pr_wtr,pr,er,an)*(-1));
```

etraair(pr,er,an)$(prdf(pr) or prrs(pr) or prref(pr))..	Demand for the air transport

```
  A_TRAAIR(pr,er,an)   =E= theta_dtraair(pr,er,an)  * (p_trans0(pr,er,an)/p_traair0(pr,er,an))  * A_TRANS(pr,er,an) *
                           P_TRANS(pr,er,an)/P_TRAAIR(pr,er,an)  *p_traair0(pr,er,an)   /p_trans0(pr,er,an))**sigmatra(pr,er,an);
```

eptraair(pr,er,an)$(prdf(pr) or prrs(pr) or prref(pr))..	Unit cost of air transport

```
  P_TRAAIR(pr,er,an)   =e= P_IO(pr_air,er,an)*exp(tgm(pr_air,pr,er,an)*(-1));
```

HOUSEHOLD CONSUMPTION SUBMODEL

ephcfv(fn,er,an)$(a_hcfv0(fn,er))..	

```
  P_HCFV(fn,er,an)     =e=  sum(pr, thcfv(pr,fn,er,an)/(exp(tgqtchn(pr,fn,er,an))) *
                                      (P_HC(pr,er,an) + txsubnrj_HC(pr,fn,er,an)*P_WPI(an)/p_wpi0))
                     + sum(ghga, sum(prfuel, TXENVHDG(ghga,fn,er,an)*bech(ghga,prfuel,fn,er,an)*aerh(prfuel,fn,er,an)*
                                   eafh(prfuel,fn,er,an)* A_HCFVPV(prfuel,fn,er,an))/A_HCFV(fn,er,an));
```

eHCFVPV(pr,fn,er,an)..	

```
  A_HCFVPV(pr,fn,er,an) =e=  thcfv(pr,fn,er,an)/exp(tgQTCHN(pr,fn,er,an)) * A_HCFV(fn,er,an);
```

eHCV(pr,er,an)..	

```
  A_HC(pr,er,an)       =e=  sum(fn, A_HCFVPV(pr,fn,er,an));
```

eHCFV(fn,er,rtime)$(an(rtime))..	Demand for Non Durables and Durables Goods

```
  A_HCFV(fn,er,rtime)   =e=   chcfv(fn,er,rtime) + bhcfv(fn,er,rtime)/P_HCFV(fn,er,rtime)*
                              (V_HCDTOT(er,rtime) - sum(fr, P_HCFV(fr,er,rtime)*chcfv(fr,er,rtime)));
```

ENERGY EFFICIENCY STANDARDS

build_energysave_h_eq(pr,er,an)$(sum(fn, es_h_expenditures(fn,er,an)) ne 0)..	Demand for sectors that delivers the energy saving

```
  P_IO(pr,er,an) * A_BUILD_ENERGYSAVE_H(pr,er,an)  =e=  sum(fn, build_energysave_h_coef(pr,fn,an) *
                                                             es_h_expenditures(fn,er,an));
```

build_energysave_f_eq(pr,er,an)$ (sum(br, es_renov_expenditures(br,er,an)) + sum(br, es_equip_expenditures(br,er,an)) ne 0)..	Demand for sectors that delivers the energy saving

```
  P_IO(pr,er,an) * A_BUILD_ENERGYSAVE_F(pr,er,an)    =e=
    build_energysave_f_renov(pr,er,an) * sum(br,  es_renov_expenditures(br,er,an))
 + build_energysave_f_equip(pr,er,an) * sum(br, es_equip_expenditures(br,er,an));
```

etgen(pr,br,er,an)$(prfele(pr))..	Energy productivity in firms

```
  TGEN(pr,br,er,an) =e= tge(pr,br,er,an) + TGE_RENOV(br,er,an) + TGE_EQUIP(br,er,an) + exo_ee_gains(br,er,an);
```

etge_renov(br,er,an) $(prfe(br) and sum(prfele, a_io0(prfele,br,er,byear)) and sw_renov(br,er,an))..	Energy productivity from renovation

```
   TGE_RENOV(br,er,an) =e= (1 + cum_es_renov(br,er,an)/((sum(prfele, p_io0(prfele,er,an) *a_io0(prfele,br,er,byear))
                                     /a_xd0(br,er,byear)) * A_XD(br,er,an)))**srenov(br,er,an) - 1;
```

etge_equip(br,er,an)$(prfe(br) and sum(prfele, a_io0(prfele,br,er,byear)) and sw_equip(br,er,an))..	Energy productivity from equipment

```
  TGE_EQUIP(br,er,an) =e= (1 + cum_es_equip(br,er,an)/((sum(prfele, p_io0(prfele,er,an) *a_io0(prfele,br,er,byear))
                                     /a_xd0(br,er,byear)) * A_XD(br,er,an)))**sequip(br,er,an) - 1;
```

etgqtchn(pr,fn,er,an)..	Energy productivity in household

```
  TGQTCHN(pr,fn,er,an) =e= tgqtch(pr,fn,er,an) + TGH_HOUSE(pr,fn,er,an) + exo_tgqtch(pr,fn,er,an);
```

etghouse(pr,fn,er,an) $(prfele(pr) and fn_enhous(fn) and (sw_renov_hh(er,an) or sw_equip_hh(er,an)))..	Energy productivity from renovation and equipment

```
  TGH_HOUSE(pr,fn,er,an) =e=  [(1 + cum_es_h_renov(er,an)/((sum(prfele, p_hc0(prfele,er) * a_hcfvpv0(prfele,fn,er))
                                       /a_hcfv0(fn,er)) * A_HCFV(fn,er,an)))**shhrenov(er,an) – 1              ]$sw_renov_hh(er,an)
                                     + [(1 + cum_es_h_equip(er,an)/((sum(prfele, p_hc0(prfele,er) * a_hcfvpv0(prfele,fn,er))
                                       /a_hcfv0(fn,er)) * A_HCFV(fn,er,an)))**shhequip(er,an) – 1              ]$sw_equip_hh(er,an);
```

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